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THE

QUARTERLY JOURNAL

OF THE

GEOLOGICAL SOCIETY OF LONDON.

EDITED BY

THE ASSISTANT-SECRETARY OF THE GEOLOGICAL SOCIETY.

Quod si cui mortalium cordi et curæ sit non tantum inventis hærere, atque iis uti, sed ad ulteriora penetrare; atque non disputando adversarium, sed opere naturam vincere; denique non belle et probabiliter opinari, sed certo et ostensive scire; tales, tanquam veri scientiarum filii, nobis (si videbitur) se adjungant.
—*Novum Organum, Præfatio.*

VOLUME THE SEVENTIETH.

1914.

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SESSION 1913–1914.

1914.

Wednesday, April	....	29*
„ May	....	13 —27*
„ June	....	10 —24*

[*Business will commence at Eight o' Clock precisely.*]

The asterisks denote the dates on which the Council will meet.

THE

QUARTERLY JOURNAL

OF

THE GEOLOGICAL SOCIETY OF LONDON.

VOL. LXX.

1. GEOLOGICAL SECTIONS *through the* ANDES *of* PERU *and* BOLIVIA: I—*From the* COAST *at* ARICA *in the* NORTH *of* CHILE *to* LA PAZ *and the* BOLIVIAN 'YUNGAS.' By JAMES ARCHIBALD DOUGLAS, M.A., B.Sc., F.G.S. (Read November 5th, 1913.)

[PLATES I–X.]

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I. INTRODUCTION.

THIS paper deals with the geological structure of a part of the South American Andes, as illustrated by a horizontal section drawn from the port of Arica in the extreme north of Chile (formerly Peruvian territory), across the mountain-ranges or 'Cordilleras,' to

the 'Montaña,' or forested region of the Amazon basin, known as the Bolivian Yungas. It is the partial result of two years' geological exploration in Peru, undertaken on behalf of Mr. W. E. Balston, F.G.S., who, being impressed during his travels by the geological features of the country, was good enough to send me out for the Oxford University Museum to study them in greater detail. I was accompanied for fifteen months by Mr. J. R. Thomas of Montana (U.S.A.), who, after his valuable help in the field, I much regret, has been unable to assist me further in the study and publication of our results.

At Mr. Balston's suggestion, we commenced work in the south of the district, following the route of the new Arica–La Paz railway, which at the time of our visit was in course of construction. Unfortunately, the line passes for the greater part of its length over igneous rocks and barren sediments, furnishing little in the way of palæontological evidence, and thus compares somewhat unfavourably with the more fossiliferous sections of our northern traverses. This southern section, however, has a particular interest on account of its historical associations, since it is practically coincident with a section first described in 1842 by A. d'Orbigny, who travelled to La Paz by the old Bolivian high road from Tacna. The same route was followed later by P. J. A. Pissis in 1856 and David Forbes in 1867. These authors differed somewhat widely in their interpretations of the section, and a summary is given in Forbes's paper, which was published in the Journal of this Society. Among more recent travellers who have contributed to our knowledge of the district are Prof. G. Steinmann, with his colleagues Dr. H. Hoek and Baron A. von Bistram, Prof. Hauthal, Sir Martin Conway, Dr. J. W. Evans, and several others. Local scientific men in Bolivia are now beginning to take an interest in the geology of the country, and much useful work is being done by Señores Posnansky, Sundt, and others under the able leadership of Dr. Manuel V. Ballivian, Minister of Colonization and Agriculture. Señor Escutti Orrego, an ardent Chilian geologist, has also furnished us with a number of fossils from the Morro de Arica, while another of his collections is preserved in the British Museum (Natural History) at South Kensington.

II. General Outline of the Physiography of the Peruvian and North Bolivian Andes.

The Pacific border of this portion of the South American continent falls naturally into three well-defined regions, differing markedly in their physical and climatic conditions:—

(i) The rainless deserts of the coastal plains.
(ii) The mountainous district, or 'Sierra,' comprising the 'Cordilleras' or chains of the Andes, with their intervening high-level valleys and plateaux.
(iii) The thickly-forested region, or 'Montaña,' of the Amazon basin.

(i)—The coastal deserts, as has been clearly shown by Dr. G. I. Adams, in his 'Outline Review of Peruvian Geology,'

occupy three separate areas, between which the foothills are continued to the ocean border: namely, a northern district, including the plains of Trujillo and Piura; a south-central in the neighbourhood of Pisco; and a southern, comprising the pampas of Mollendo and Tacna.

(ii)—In Southern Peru and the district described in the present paper, the mountain-system of the Andes consists of two main chains—a western, the 'Cordillera Occidental,' which is the continuation of the main Chilian range, and an eastern, the 'Cordillera Oriental.' Between these two lies the elevated plateau known as the 'Altaplanicie,' the site of Lake Titicaca. Northwards the chains unite in latitude 14° S., forming the Vilcanota knot, to divide again into three main branches—recognized by Raimondi as a Western 'Cordillera,' following the general direction of the coast; a Central, separating the valleys of the Apurimac and Mantaro Rivers from that of the Urubamba or Vilcamayo; and an Eastern separating the Urubamba from the Madre de Dios. In the neighbourhood of Cerro de Pasco the chains reunite to form a second mountain-knot, dividing northwards once more into three. Here the Western Cordillera at its southern end, where it diverges from the knot, splits into two minor parallel chains, the 'Cordillera Negra' and the 'Cordillera Blanca,' separated by the valley of Huaylas. This valley at first follows the strike of the chains to the north-west, but in latitude 9° S. cuts the 'Cordillera Negra' almost at right angles, to enter the sea in the Bay of Santa north of Chimbote.

The main Central Cordillera separates the valley of the Marañon from that of the Huallaga; while the Eastern separates the latter from the Ucayali.

(iii)—The third region comprises the vast forested area of the Amazon basin, almost impenetrable save along the navigable rivers and the narrow trails leading to gold or rubber camps. The descent from the 'Sierra' is rapid, and the whole country soon becomes clothed in dense tropical vegetation. Rare open spaces, or *pajonales*, devoid of trees, enable one, however, to obtain occasional glimpses of the distant landscape. A great part of this country has been explored by Dr. J. W. Evans, who describes a number of small parallel chains running in a north-westerly direction parallel to the main 'Cordillera.' The first of these, bounding the valley of the River Coroico on the east, he has named the Cusali Range.

III. Main Topographical Features of the Country included in the First Section. (Arica to the Bolivian 'Yungas.') (See Map, Pl. X, fig. 2.)

Our first main traverse, the results of which are included in the following pages, was made through the extreme north of Chile, formerly Peruvian territory, and a part of Bolivia, following the present line of railway as far as La Paz, whence it was continued

over the Eastern Cordillera into the district known as the North Yungas.

This railway commences at the port of Arica, which is situated in lat. 18° 29′ S. and long. 70° 20′ W., just at the point where the main trend of the Pacific coast-line of South America changes from a north-and-south direction to north-west by south-east. After following the shore for a few miles, it turns inland up the fertile valley of the Llutah River to Poconchile (kilometre 37; altitude 1772 feet).

From this point a steep winding ascent is made over desert foot-hills and the so-called 'Pampa Colorada' to Central (kilom. 70; alt. 4859 feet); it is continued eastwards with increasing grades and a 40-kilometre stretch of rack-and-pinion line, over typical 'bad lands' composed of numerous small and steep-sided dry rocky valleys or quebradas, until more or less level ground is reached above Huaylas (kilom. 135; alt. 12,797 feet). We are here in the region of the Western Cordillera, a vast range of giant extinct volcanoes which rise abruptly from the high-level plateau.

On the south are visible the mighty peaks of Sajama (21,423 feet) and the Payachatas or Twins; while close at hand, separated from us by the deep Jamiraya gorge, through which flow the head-waters of the Llutah River, stands the 'Nevada de Putre' or Taapaca (19,145 feet); see Pl. I.

Following the line past the swamps of Ancachulpa and the salt lake Laguna Blanca to the Bolivian frontier, we pass in close proximity to the southern base of Mount Tacora (19,520 feet); while Mount Chupiquiña (18,855 feet) and other high peaks are seen succeeding one another in the north.

After crossing the frontier (kilom. 205; alt. 13,321 feet), the railway makes a gradual descent to the valley of the Mauri River (kilom. 250; alt. 12,842 feet), which is followed for some 50 miles until it enters the Desaguadero at the village of Calacoto (kilom. 316; alt. 12,485 feet). The latter river flows out of Lake Titicaca, and drains southwards into Lake Poopoo, from which there is no visible outlet.

From Calacoto onwards the country is more or less broken up by small parallel chains, rising to no great height when compared with the main 'Cordilleras,' and separated one from the other by wide alluvial tracts, which were originally, without a doubt, the site of a great system of lakes: of these Lake Titicaca still in part survives, and furnishes us with clear evidence of its former magnitude. A conspicuous landmark in this district is the Alto de Comanche (kilom. 364), a steep-sided mountain, which rises to a considerable altitude above the level of the plateau.

Beyond Viacha (kilom. 416; alt. 12,635 feet),[1] where connexion is made with the Huaqui & Antofagasta railway, the whole surface

[1] Most of the altitudes in this part of the section are somewhat lower than those given by Forbes. They are taken from my personal observations with an aneroid, and from a 'Guide' to Bolivia recently issued by the Government. See Bibliography, § VI, p. 49.

of the country is covered by a great sheet of alluvium, forming a flat unrelieved desert: this ends abruptly in the valley of La Paz, a mighty gorge with almost vertical sides, carved out of the alluvial plateau and separating it from the high peaks of the Eastern Cordillera, which, rising to altitudes of over 21,000 feet, bound it on the east. The view, from the barren plain or Altaplanicie, of the fertile valley, with the city of La Paz 1600 feet or more below, is one of unsurpassed beauty.

From La Paz our traverse was continued eastwards up the valley of Chuquiagillo, renowned for its rich gold-washings. The road crosses the pass at Huacuyo (15,550 feet), descending rapidly to Pongo [36 kiloms.] and the custom-house of Unduavi (10,427 feet). From here, after rising over the spur of Sillutincara (11,600 feet), a descent of nearly 5000 feet in 12 miles is made to Bella Vista [65 kiloms.; 6890 feet]. From Sandillani [69 kiloms.] the road once more descends rapidly down the winding Tunca Queuta (Aymara = 'ten turns') to the River Chairo, which unites, with the Elena and the Yoloza to form the Coroico, one of the chief tributaries of the Caca. Leaving the village of Coroico (6530 feet) on the right, and crossing the river, one reaches the hacienda of Mururata a short distance farther on [100 kiloms.; 3390 feet]. This forms the eastern termination of our first section.

For a clearer understanding of the geological features of the main section, it was found necessary to make a number of subsidiary journeys in this part of the country, the most important of which are described in the following paragraphs.

That portion of the railway-section that lies between Huaylas and Poconchile (see Pl. X, fig. 2) was examined when returning to the coast, since on our journey inland we proceeded from the latter village up the branch-line to Molino, and thence continued up the valley of the Llutah to Jamiraya, at the western end of the gorge of that name; finding it impossible to proceed farther, owing to obliteration of the trail, we ascended the southern side of the valley by the cuesta[1] of Cuescolla to the village of Putre, which lies at the foot of Mount Taapaca (Pl. I).

Recrossing the Llutah near Patapatani, we once more reached the railway-cuttings above Huaylas. On our return journey we paid a second visit to the Jamiraya gorge, descending into it by the cuesta of Socoroma at its deepest part above Jamiraya and at Ancolocalla, a few miles up river.

This gorge at Patapatani, its upper or eastern end (Pl. II), is about 250 feet deep, with vertical sides; from here it is continued for a distance of some 10 miles to Jamiraya, attaining a maximum depth of over 6000 feet. Its sides are so steep, being often little short of vertical, that it is only possible to descend to the river at one or two places. At one time, the idea was conceived of carrying

[1] Cuesta (Spanish = 'slope') is here used to denote a mountain-spur up which a steep trail is cut in a zigzag manner.

through it the Arica–La Paz Railway; wherefore Mr. H. Schumacher, of Tacna, the locating engineer of the line, cut a narrow trail, with native labour, from one end to the other, and accomplished its survey for the first time. The danger and cost of construction, however, were found to be too great, so the scheme was abandoned; and at the time of our visit landslides had almost obliterated the old trail, which in most places was nothing more than a narrow ledge cut in the vertical face of rock.

It is now, therefore, impossible to go more than a short distance up or down stream from the two spots to which a descent can be made. One cannot but regret the loss to science of so magnificent a natural section; for, the line to the north being now completed, no one is ever likely again to spend time or money in constructing another trail in so inaccessible a region.

After visiting the Jamiraya gorge, we crossed from Poconchile to Tacna, and proceeded inland up the valley of Palca—for the purpose of comparing our results with the section described by A. d'Orbigny, Pissis, and Forbes.

We may turn now to the eastern part of the main section. In the following year (1911) we journeyed from Puno round the western shores of Lake Titicaca to the Copacabana Peninsula and the Island of the Sun; and thence crossing the Straits of Tiquina, we proceeded southwards to La Paz.

Finally, on two separate occasions we explored the country south of Calacoto along the Desaguadero River, in the neighbourhood of Callapa and Ulloma.

IV. Geological Description of the Section from Arica to the Bolivian 'Yungas.' (See section, Pl. X, fig. 1.)

A most complete and detailed description of this district was given by David Forbes, in a paper published in 1861 on the Geology of Bolivia & Southern Peru[1]; and, as much of his work is in close agreement with my own observations, I shall here confine myself (in order to avoid useless repetition) mainly to those points concerning which new results have been obtained, or where the interpretations of that author appear to be open to criticism.

In dealing with a section of such magnitude, I have deemed it advisable to describe the formations in the order in which they are met with in traversing the country, but not in the actual order of superposition, since the main structural features seem to be of wider interest than the mere stratigraphical sequence, and my ultimate object is a comparison of a number of sections through the Peruvian Andes. As each formation is met with, however, those fossils that are of interest will be discussed in the palæontological notes.

The petrographical descriptions of the microscopic rock-sections must only be regarded as preliminary observations; for, in the

[1] See Bibliography, § VI, p. 49.

light of recent research on the distribution of igneous rocks, I have decided to make at some future date a more detailed study of the igneous rocks of Peru taken as a whole.

For the purposes of description, this first or southern section may be conveniently divided into three parts:—

(i) The Mesozoic sediments of the coastal region with their contemporaneous igneous rocks, the intruded core of granodiorite, and the overlying recent volcanic deposits of the Western Cordillera.

(ii) The volcanic beds of the Mauri River, the Mesozoic and Palæozoic rocks of the Altaplanicie and Titicaca district, the line of dioritic intrusions, and the Pleistocene deposits of the Desaguadero River.

(iii) The Palæozoic rocks and granitic core of the Eastern Cordillera and the Amazon slopes.

(i) The Geological Structure of the Coastal Region and the Western Cordillera.

(*a*) The Mesozoic deposits and the contemporaneous igneous rocks.

A magnificent section of stratified Mesozoic rocks is exposed along the whole coast of Northern Chile, the cliffs rising abruptly from the shore and being plainly visible from the coasting steamers. They terminate northwards in the Morro de Arica, a steep hill south of the port of that name, beyond which the ocean is bordered by a broad strip of coastal desert. This hill forms the starting-point of our first transverse section through the Andes.

The bulk of the Morro is made up of volcanic rocks, with certain stratified beds appearing at the base and towards the summit, the true age of which has always been a matter of some doubt. They were originally coloured as Carboniferous by A. d'Orbigny,[1] from the supposed occurrence of *Productus* in limestone included in the lava. Forbes,[1] though apparently obtaining no palæontological evidence, classes them tentatively with the Upper Oolitic Series, with the following comment:—

> 'This evidence [of A. d'Orbigny] does not appear to me sufficiently conclusive to warrant its being separated from the other strata, which appear continuous and which are decidedly of Upper Oolitic age,—more particularly as we have no example of the occurrence of Carboniferous beds anywhere along the coast of the Pacific in South America.' (Q. J. G. S. vol. xvii, 1861, p. 51.)

Though the latter statement will be shown in a future paper to be incorrect, the conclusion arrived at was more or less accurate.

Prof. E. Suess [2] suggests a comparison of the Morro de Arica with the Cretaceous mountain-zone of Tierra del Fuego, which is said in places to assume a Palæozoic aspect.

In 1909 Señor Escutti Orrego,[1] of Arica, published a short

[1] See Bibliography, § VI, p. 49.
[2] 'The Face of the Earth' Engl. transl. vol. i (1904) pt. 2, chapt. ix, p. 527.

pamphlet on the fossils of the Morro, and, from the supposed occurrence of *Rhynchonella tetrahedra*, assigned to these beds a Liassic age. In a later manuscript copy he alters his opinion, owing to the discovery of further evidence, and places them in the Oxfordian. I have to thank this author for showing me the fossiliferous horizons, and putting the whole of his interesting collection at my disposal. Among the specimens that he has sent me since my return to England are a few ammonites, an examination of which leaves little doubt that his later determination is the correct one. (See p. 10.)

The Morro rises almost vertically along its seaward face to a height of over 450 feet, and, as its sloping sides are almost completely covered by sand, a correct delineation of the vertical succession of the beds is a matter of some difficulty, although this is a point of minor importance as compared with the estimation of their age. At the base of the hill are exposed about 70 feet of black and olive-green shales, dipping 10° southwards, in which fossils are of rare occurrence and badly preserved. These include crushed lamellibranchs (one of which suggests *Gryphæa*), large Terebratuloid shells, and poor casts of *Rhynchonella*. These beds become slightly more arenacous towards the top, and here Señor Escutti Orrego has obtained two fairly-good specimens of ammonites (*Macrocephalites* sp.).

The basal shales are altered at their summit to a hard flinty rock by an overlying bed of porphyritic augite-andesite, 150 feet thick, and exhibiting well-marked pillow-structure (Pl. III, fig. 1), the origin of which is discussed below. The spaces between the pillows are filled up with a black shale or mudstone, slightly metamorphosed, but containing in abundance well-preserved lamellibranchs (*Posidonomya*). This deposit is continued for a few feet above the top of the first or main lava, containing fossils similar to those found between the pillows and an occasional ammonite (*Cosmoceras* sp.).

It is succeeded by thinly-bedded, reddish, sandy shales, with veins and layers of gypsum, having a total thickness of 150 feet, or about equal to that of the main lava.

Along the north-eastern slope of the Morro, towards the base of this series, is seen a small sill of compact greenish-grey dolerite, which has the form of a lenticular or wedge-shaped intrusion about 9 feet thick, thinning out eastwards and altering the shales both above and below it. Pillow-structure is completely absent from this rock, and it differs essentially from the main mass described below.

Above the red shales more beds of pillow-lava are visible, occurring at several horizons. Towards the summit appear further red shales, followed by about 2 feet of impure limestone containing *Serpulites*, badly-preserved lamellibranchs (*Pecten*, *Modiola*, etc.), and occasional Echinoid spines (probably *Cidaris*).

Finally, the hill is capped by another lava-bed, similar in nature to the main mass, but of a reddish colour and much weathered.

Palæontological Notes.

With one or two exceptions, the fossils obtained from the stratified beds of the Morro are badly preserved, and it is impossible to make exact specific determinations. The general assemblage, however, points to a Bathonian facies at the base, with a transition into Callovian and Oxfordian, and possibly still higher beds, at the summit of the hill.

Faunal List.

Terebratula cf. *maxillata* Sow.	*Gryphæa* sp.
Rhynchonella cf. *obsoleta* (Sow.).	*Macrocephalites* sp.
Flabellothyris sp.	*Cosmoceras* aff. *ornatum* Schloth.
Pecten sp.	*Serpulites*.
Modiola sp.	*Cidaris* spines.
Posidonomya escuttiana, sp. nov.	

Posidonomya escuttiana, sp. nov. (Pl. VIII, fig. 7.)

This species, which occurs abundantly in the black shales surrounding the 'pillows' in the main mass of lava, has the following characters:—Shell thin and transversely oval, though slightly oblique; very gently convex, the greatest convexity being along a line drawn from the umbo to the lower posterior angle.

Hinge-line straight, not much shorter than the greatest width of the shell. Both anterior and posterior borders rounded. Umbones small, situated at about a third of the length of the hinge-line from its anterior end.

Surface ornamented with concentric flattened folds separated by grooves. These become gradually broader towards the lower border, and are crossed radially by irregular pustulose wrinkles, ill-defined in the young shell, but becoming more pronounced with age. The wrinkles on one fold at first tend to be distinct from those on the next, but towards the lower margin frequently pass across the intervening furrow. They are but feebly developed on the posterior and anterior borders of the shell.

I have been unable to find any other example of the genus bearing this peculiar type of ornamentation, which therefore appears to be sufficiently characteristic to warrant the introduction of a new specific name.

Macrocephalites sp. (Pl. VIII, figs. 1 *a* & 1 *b*.)

The general form of this species is that of a small *Macrocephalites*, showing certain affinities with the Sphærocerates.

The whorls increase in size rather rapidly, and, though not very deep, are considerably involute, being thus somewhat semilunar in cross-section. They possess a Stephanocerate type of ornament. The ribs are numerous and fine, but with no conspicuous thickening along the umbilical margin. The umbilicus is deep and crateriform, with steep sides. The suture-lines, although indistinct, do not appear to be very complicated.

Terebratula sp.

Most of the fossils from the black shales at the foot of the Morro are considerably crushed, and, although several specimens of a large Terebratuloid shell were obtained, it has been found impossible to assign them to any definite species, or to say more than that they are probably of Bathonian age and most nearly related to a type such as *Terebratula maxillata* Sow.

Rhynchonella sp.

These shells, which occur usually in the form of casts, were formerly referred to the Liassic species *Rh. tetrahedra*; if we judge from the associated fossils, however, they are probably of somewhat later age, and appear to possess closer affinities with *Rh. obsoleta* (Sow.).

The igneous rocks of the Morro.—Though mentioning elsewhere the occurrence of contemporaneous porphyries in the Oolitic Series, Forbes,[1] when he discusses the rocks of the Morro, describes the lavas as intruded sheets. In this he is followed by later writers, but the evidence summarized below appears to afford ample justification for regarding their origin as contemporaneous with the deposition of the sedimentary deposits :—

(1) The whole thickness of lava exhibits typical 'pillow'-structure, the ovoid masses being often more than 10 feet in diameter and lying with their long axes approximating to the horizontal.
(2) This structure is not a phenomenon of surface-weathering, as is shown by its continuance through a great landslip which cuts the face of the cliff, and by isolated blocks fallen on the beach.
(3) The black shales filling the spaces between the pillows contain abundant marine fossils, which are often unbroken and well preserved.
(4) The metamorphism of the shales has resulted in little more than the production of a compact hornstone selvage surrounding the individual pillows.
(5) Similar shales overlie the lava practically horizontally, and are completely unaltered—except in the immediate vicinity of the pillows (Pl. III, fig. 2).
(6) Microscopic examination of the rock of which the pillows are composed shows that the porphyritic constituents are set in a true glassy ground-mass. This would hardly be expected to occur in a subsequently intruded sheet of lava over 100 feet thick, owing to which its dimensions would necessarily undergo somewhat slow cooling.
(7) The mass cannot be regarded as composed of a series of thin intrusive sheets, which might be suggested in explanation of some of the phenomena enumerated above.

In general appearance and mode of occurrence, then, this rock presents many of the characteristic features of a typical pillow-lava, and seems to have differed little in its mode of origin from other lavas exhibiting a similar structure. It undoubtedly represents a submarine volcanic flow, which took place contemporaneously with the deposition of the shales in which the pillows are embedded; though whether the eruption itself was actually submarine or subaërial is a moot point. The abundant individuals of the genus

[1] Q. J. G. S. vol. xvii (1861) p. 36.

Posidonomya in these shales would appear to indicate a comparatively shallow-water facies, which is also suggested by the associated red sandstones with gypsum.

The glassy ground-mass of the rock is an indication of rapid cooling, and, although the outburst appears to have been more or less continuous during the building-up of the whole sheet, it was doubtless of fairly long duration: thus each layer of pillows had time to undergo considerable loss of temperature before being covered by succeeding layers. In many cases, however, the individual pillows had not become sufficiently rigid to resist deformation by the superincumbent mass.

The absence of any marked metamorphism of the shales, except the actual coating of the pillows, suggests that the shell-bearing mud was in part deposited subsequently to the extrusion of the lava, and gradually found its way through the interstices into its present position, thus accounting for the presence of well-preserved lamellibranchs, which otherwise, from their fragile nature, could hardly have escaped crushing.

Although vesicular or amygdaloidal structure is occasionally noticed, it is by no means a characteristic feature of the rock, which in this respect (apart from microscopical characters) appears to differ essentially from many other well-known occurrences, such as that described by Mr. Clement Reid & Mr. H. Dewey from Port Isaac in Cornwall.[1] This, however, is probably a feature due less to environment and mode of origin, than to the chemical composition and physical conditions of the molten lava.

The chief points of interest about this rock, as kindly pointed out to me by Dr. J. S. Flett, are its extraordinarily fresh condition, with complete absence of any trace of albitization such as occurs in the true spilites, and the fact that its petrographical character is distinctly of a Pacific type.

Mr. O. H. Evans has mentioned the occurrence of pillow-lavas of probably Mesozoic age in the Taltal coast-region of the Atacama Desert in Chile[2]; but I believe that they have not yet been described in detail.

With regard to the well-known association of radiolarian cherts with pillow-lavas, no systematic search for these organisms has yet been attempted in the shales of the Morro, as such detailed work seems beyond the scope of the present paper. It is a subject, however, which I hope to investigate later.

Petrographical Descriptions.

(A_1 & A_2)[3] Enstatite-andesite from the Morro de Arica, Chile. (Pl. VII, fig. 3.)

Macroscopic characters: The rock of which the pillows are

[1] Q. J. G. S. vol. lxiv (1908) p. 264. [2] *Ibid.* p. 270.

[3] These index-letters refer to microscopic slides and hand-specimens from the collection of igneous rocks made during the expedition, now preserved in the University Museum, Oxford.

composed may be described as a compact porphyritic enstatite-andesite, varying from the centre of the individual masses, where it has a black basaltic appearance, to the exterior, where the ground-mass is of a greyish colour with conspicuous porphyritic crystals of clear plagioclase (showing lamellar twinning) and black pyroxene. This change of colour, which is often abrupt, appears to be in some degree due to weathering (though the constituent minerals are remarkably fresh), but chiefly to the segregation of the iron-ores towards the centres of the pillows. Small amygdules of calcite and silica, both crystalline and amorphous, are sometimes present. (Specific gravity = 2·74.)

Microscopic characters: Phenocrysts of plagioclase, with rhombic and monoclinic pyroxenes, in a glassy ground-mass.

The plagioclase occurs in large, idiomorphic, tabular crystals showing Carlsbad and polysynthetic twinning and occasional zonary structure. In a specimen taken from near the exterior of a pillow (A_1) it is slightly weathered; but, in one nearer the centre (A_2), it is remarkably clear and fresh, though sometimes containing inclusions of the ground-mass. The refractive index is distinctly higher than that of Canada balsam, and the extinction-angles on sections cut perpendicular to the albite-lamellæ range up to 30° (labradorite).

The pyroxene-phenocrysts are represented by both rhombic and monoclinic varieties, pale green to colourless, the former (near enstatite) showing very faint pleochroism and low double refraction. It is sometimes intergrown with monoclinic augite, or the latter may occur in the form of a thin secondary marginal growth round a rhombic crystal. In the more weathered example (A_1) such a margin frequently remains, while the rhombic interior has been completely converted into a fibrous network of serpentine.

The ground-mass is hyalopilitic, consisting of brown isotropic glass, crowded with microlites and skeleton-crystals of felspar, pyroxene, and magnetite. In A_2 it is almost opaque in ordinary light, owing to dissemination of magnetite dust, which seems to be segregated towards the centres of the pillows, where beautiful examples of skeleton-crystals are abundant. Many yellowish-green patches occur, and between crossed nicols show spherulitic structure. The felspar-microlites are frequently grouped in sheaf-like bundles. Circular amygdaloids occur, sparingly filled with calcite mosaic.

(A_3) Dolerite; intrusive sill, Morro de Arica.

Macroscopic characters: A compact, greenish-grey, micro-crystalline rock without phenocrysts, composed mainly of felspar with black grains of pyroxene. (Specific gravity = 2·72.)

Microscopic characters: A much-altered rock, the bulk of which consists of a felted mass of felspar-laths and pale yellowish-green chlorite. The felspar appears to be chiefly oligoclase, with Carlsbad and polysynthetic twinning. Extinction-angles ranging from 0° to 5°.

Augite colourless to pale green, occurring as small irregular grains in the ground-mass with no definite crystal outlines.

Ilmenite in black grains, altering into sphene. Chlorite abundant, in irregular yellowish-green pleochroic patches, which wrap round the felspar-laths so as to suggest an original ophitic structure. Epidote and calcite occur sparingly.

As we pass inland from the coastal section, the whole surface of the country traversed by the railway is covered by sandy deserts formed by the weathering of a thick mantle of volcanic lava and tuff, and all traces of the underlying Mesozoic sediments are completely obscured, except along the valleys of the Llutah and Palca Rivers, which have been eroded to a sufficient depth to bring the Mesozoic deposits once more to light.

The Llutah enters the sea a few miles north of Arica, and, on proceeding up its valley, we first meet with stratified Mesozoic rocks between Molino and Cata: they consist of a thick series of barren black, brown, and olive-green shales having a more or less constant westward dip, and much altered by the intrusive core of plutonic rock, with the production of numerous mineral veins. A thick vertical succession was passed over in ascending the cuesta of Cuescolla to Socoroma, but no evidence of fossil remains was discovered.

Farther east, at Ancolocalla, similar altered shales and thin limestones, dipping 50° south-westwards, are again visible at the very bottom of the Jamiraya gorge, which is some 5000 feet deep at this point. Here faint traces of fossils were recorded—chiefly small *Posidonomyæ*, similar to those obtained from the Morro de Arica. Penetrating the shales at this locality and cutting across their bedding-planes was found a thick dyke or intrusion of quartz-hypersthene-norite, the true dimensions of which, owing to the inaccessibility of the gorge, could not be determined. The occurrence of this rock is of considerable interest, for it may possibly represent the original source from which the pillow-lavas of the coast-section were extruded, and thus be regarded as their plutonic equivalent. It is absolutely distinct from the intrusive core of granodiorite described on p. 14, which appears to be of much later date; and I know of no other similar occurrence in any part of the country.

(A_{15}) Quartz-hypersthene-norite; Ancolocalla, Llutah River (Chile).

Macroscopic characters: A holocrystalline, compact, even-grained, grey to black rock, composed of plagioclase, slightly iridescent, and black pyroxene, with a little quartz. It is difficult to discriminate between the constituent minerals. (Specific gravity = 2·77.)

Microscopic characters: Holocrystalline, of somewhat coarse texture, composed essentially of plagioclase, rhombic and monoclinic pyroxenes, quartz, and iron-ores.

Plagioclase, in hypidiomorphic crystals, fairly fresh, but with a faint pinkish colour, due to abundant dust-like ultra-microscopic inclusions of iron-ores arranged parallel to the vertical axis. Twinning according to polysynthetic and pericline laws. The extinction-angles indicate acid labradorite.

Pyroxenes: Monoclinic, diallage, of a faint greenish colour, without definite crystal outlines; numerous inclusions of ilmenite and apatite. Rhombic, hypersthene, showing straight extinction, and faint pink and green pleochroism, altering into yellowish-green serpentine. Both rhombic and monoclinic forms frequently exhibit marked schillerization.

Apatite is fairly abundant, in well-developed prisms and long needles. Ilmenite is abundant in large irregular grains. Biotite occurs sparingly, as a minor accessory. Quartz is found as an original constituent, the last product of consolidation, in some little quantity.

(*b*) The plutonic core of the Western Cordillera.

The erosion of the river-valleys which has brought to light the Jurassic sediments has also laid bare the underlying mass of plutonic rock, by which they have been penetrated and metamorphosed. This mass, which has the form of an elongated batholith, with its long axis lying approximately parallel to the coast (that is, north-west and south-east), may be regarded as the deep-seated core of the Western Cordillera. In the district now described the actual date of the intrusion can only be determined as post-Jurassic, though farther north in Peru similar (and possibly identical) plutonic rocks penetrate fossiliferous Cretaceous beds, and are, therefore, probably of Tertiary age, doubtless representing a comparatively late phase in the development of the mountain-ranges of the Andes.

In the Llutah Valley above Molino, the plutonic core is first seen near Tiñares, and is well exposed between Cata and Palmani. It is again met with at the bottom of the gorge at Jamiraya, although no longer visible where the river is once more accessible at Ancolocalla, a few miles away to the east.

The composition of the rock varies considerably in different localities, which probably accounts for the different views concerning its nature expressed by various authors. A. d'Orbigny regarded it as a granite of very early date; while Forbes, noting the metamorphism of the Jurassic sediments, classed it as a pre-Cretaceous diorite.

A certain amount of differentiation appears to have taken place previous to the intrusion, for it is possible to distinguish a more basic type of rock representing the portion of the magma that consolidated first, and a more acid later type which frequently includes rounded fragments of the former. In many cases these 'cognate xenoliths' are so numerous as to alter completely the appearance of the rock. Above Cata, in fact, the basic xenoliths formed about a quarter of its bulk.

The latest product of consolidation is represented by a series of

highly-acid pegmatite-veins, consisting essentially of quartz, orthoclase, and tourmaline, with a little topaz.

The basic type appears to be more completely developed towards the west of the main core, and ascending the river-valley becomes progressively more acid.

The following description represents the general facies of the rock between Tiñares and Cata :—

(A_9) Macroscopic characters: A holocrystalline even-grained rock of granitic texture and greyish colour, with rather a high percentage of ferromagnesian minerals.

Pale-green to white plagioclase, pink orthoclase, the former predominating; dark-green hornblende and black biotite. Quartz not very obvious or abundant, but never completely absent, as Forbes erroneously stated. (Specific gravity = 2·73.)

Microscopic characters: Holocrystalline, hypidiomorphic structure.

Quartz not very abundant, allotriomorphic.

Orthoclase turbid, and plagioclase fairly clear in ordinary light; the latter in excess over the former, and showing fine polysynthetic twinning, chiefly albite to oligoclase, with slight incipient alteration into sericite.

Biotite abundant, pleochroism deep brown to pale yellow; slight decomposition to chlorite and epidote.

Hornblende, pale green to colourless. Apatite occurs sparingly as inclusions in the biotite. Epidote after biotite, with canary-yellow pleochroism. Magnetite is fairly abundant.

(A_{11}) Palmani, Llutah River.

A rock similar to that just described, but of a more acid nature.

The felspars are present in about equal proportions, and the orthoclase, which occasionally tends to be porphyritic, gives a decided pink colour to the hand-specimen. Quartz is more abundant, but never very obvious. A slightly lower percentage of biotite and hornblende is found. (Specific gravity = 2·68.)

Microscopic characters: Quartz fairly plentiful, often forming pegmatitic intergrowths with the felspar.

Orthoclase equal to, or in excess of, the plagioclase, and commonly intergrown as perthite. The alteration of the felspars, which usually commences in the interior of the crystals, results in the formation of flakes of sericite.

Biotite, hornblende, epidote, and magnetite as in A_9.

Some inclusions of zircon, with pleochroic halos, occur in the biotite.

(A_{44}) Tourmaline-pegmatite; Cata, Llutah River.

This vein consists essentially of clear quartz, pink orthoclase, and tourmaline in individual crystals or radiating aggregates.

Microscopic characters: Quartz clear, fluid inclusions abundant with mobile bubbles, pegmatitic intergrowth with

orthoclase; the latter mineral occurs in Carlsbad twins, and is very turbid, showing decomposition into kaolin and sericite. Plagioclase showing albite-twin lamellation, rare.

Tourmaline abundant, in large crystals, with blue and brown pleochroism. Some biotite and a little muscovite.

Magnetite is fairly abundant. Epidote and chlorite occur sparingly.

(A_{58}) Tourmaline-vein; Jamiraya, Llutah River.

Microscopic characters: An irregular mosaic of quartz, orthoclase, and plagioclase, with abundant tourmaline. Topaz is fairly abundant in colourless prisms.

Epidote occurs sparingly; titaniferous magnetite (altering to leucoxene) and pyrite are present, as also a little secondary calcite.

In an igneous intrusion of huge dimensions, such as a mountain-core of this nature, which has been modified probably both by differentiation and assimilation, it is obviously impossible to select one or two specimens for description or analysis as typical of the whole mass, and to which a definite name can be given. Some of the more acid examples with associated tourmaline-veins would undoubtedly be assigned to the granites or adamellites; while those with quartz sparingly developed and abundant ferro-magnesian minerals would probably be found to approach in composition the tonalites or diorites.

The general composition of these so-called 'Andes granites' has been described[1] as that of a granodiorite; and, although in the specimens from my collection the plagioclase does not appear to predominate very largely over the orthoclase, the name may conveniently be retained until further chemical analyses can be made. It is, however, used here not as a definite statement of the alkaline content, but merely as indicating the general facies of the rock, which ranges from the granites and granodiorites to the tonalites.

All theories as to the origin of these deep-seated intrusions of plutonic rock must, for the greater part, necessarily be based on speculative assumptions; and, since erosion has never penetrated them very deeply, their field-relations are limited and difficult of interpretation. Many of the leading authorities hold widely-divergent views on the subject, and it is certain that the final explanation will only be arrived at by the constructive combination of a vast number of isolated facts.

The term 'batholith' was introduced by Prof. Eduard Suess to describe those large granite-intrusions which so often form the core of great mountain-chains. They may be defined as shield-shaped masses of plutonic rock, intruded as the result of fusion of older formations (durchschmelzungsmasse), and growing broader to unknown depths. They usually penetrate the crust

[1] O. Nordenskjöld, 'Die krystallinischen Gesteine der Magellansländer' Svenska Exped. till Magellansländern, Stockholm 1901, vol. i, p. 175.

along the site of folded geosynclines, and lie with their long axes parallel to the axes of the mountain-ranges. One of the most prolific writers on this subject is Dr. R. A. Daly, who considers that the replacement has been caused partly by digestion and solution along the contact of magma and country-rock, but chiefly by the mechanical process of stoping, which is the only hypothesis that accounts for the apparent lack of chemical relation between the granite and the country-rock, impossible to explain by a doctrine of simple assimilation.

Such a mode of origin for this batholithic core seems to be in accordance with the observed facts; but, since it is elongated parallel to the general trend of the Cordillera, we are dealing here with comparatively-limited exposures afforded by the Llutah and Palca Rivers, which cut across the strike. In young steep-sided valleys of this nature, however, where the contact with the overlying rocks is to a great extent obscured by screes, much evidence is not forthcoming in support or disproof of any theory as to the relative importance of the physical process of stoping or the chemical process of assimilation. Both have probably had effect, and, in describing the core of the Western Cordillera as a batholith, I have interpreted the term in this double sense, thereby expressing my views as to its probable mode of origin. The mass is dome-shaped in transverse section, widening downwards without any visible floor, and cuts across the overlying Mesozoic deposits irrespective of their dip. The process of intrusion appears to have been essentially one of replacement rather than displacement, and I see no reason to criticize Dr. Daly's theory that this may have been in great part effected by actual mechanical stoping.

One of the most frequently mentioned objections to the theory of batholithic replacement is that, as a rule, there is little or no evidence of solution by the granitic magma. In the present case, such evidence is not wholly lacking. A few hundred yards above Cata on the south side of the river, a peculiar rock is met with, apparently passing downwards into the ordinary acid plutonic type (A_{11}). This rock has, at first sight, the appearance of a compact quartzite; but, in microscopic section (A_{10}; Pl. VII, figs. 1 & 2), it is seen to be of igneous origin and composed of a granular mosaic of quartz and felspar (chiefly orthoclase), with abundant irregular plates of hornblende and biotite, completely devoid of crystal outline and showing pronounced corrosion. It appears to represent the typical basic granodiorite, invaded and partly assimilated by a highly-acid magma. The latter has consolidated as a pegmatitic intergrowth of quartz and orthoclase in the actual process of dissolving[1] the ferromagnesian elements of the original rock. That the phenomenon is one of corrosion and not of simultaneous crystallization is particularly noticeable

[1] Instances of a similar process of solution by residual quartz were figured and described from the Gilgit granite in the Himalayas by C. A. McMahon, Q. J. G. S. vol. lvi (1900) p. 366 & pl. xxiii.

in the case of the hornblende-crystals, which not only show quartz eating its way in from the edges, but also colourless patches in the centre of the sections devoid of pleochroism, although they exhibit uninterrupted prismatic cleavage. Much of the felspar must have belonged to the original rock, but it is difficult to distinguish in this case the appearance due to corrosion from that due to pegmatitic growth. The occurrence of such a rock agrees well with Dr. Daly's statement that

'If . . . a crystallized granodiorite batholith be itself attacked by a later abyssal intrusive and in large part stoped away and remelted, the secondary magma collecting at the roof of the later batholith should be more acid than [the] granodiorite.' (Am. Journ. Sci. ser. 4, vol. xxvi, 1908, p. 45.)

From the hypothesis of overhead magmatic stoping, Dr. Daly[1] has evolved a theory for the secondary origin of certain granites by a process of differentiation, after assimilation of an acid cover by a gabbroid magma.

While agreeing with that author's views on the means by which a plutonic magma makes its way into the overlying strata, I consider that it is not advisable to attach too much importance to this latter theory, so far as my own observations go. The law of decreasing basicity seems to hold good for the whole body of the magma, just as much as for the crystallization of its component minerals, even in the absence of any assimilation. In the present case, assimilation undoubtedly appears to have taken place, and probably has largely affected the composition of the rock; but I can see no clear evidence for assuming the granite to be directly derived from a gabbroid magma by a complex process of this nature. It is true, however, that in Jurassic times the volcanic rocks of the district were of an andesitic or basaltic nature, and their plutonic equivalent may probably be regarded as the hypersthene-norite of Ancolocalla; while in post-Cretaceous times the intrusive core had attained the composition of a granodiorite or granite, and the Tertiary and recent lavas, to be described later (pp. 19 *et seqq.*), have for the most part a pronounced acid character.

Any connexion, however, between the basic magma of Jurassic times and these Tertiary acid rocks must remain purely a matter of speculation.

(*c*) The Volcanic Rocks of the Western Cordillera.

The Western Cordillera differs from the Eastern or Cordillera Real in the fact that it is essentially a volcanic range formed of numerous, more or less isolated, snow-capped, dormant and extinct volcanoes, which frequently attain heights ranging between 19,000 and 20,000 feet. The great altitudes and inaccessibility of many of these peaks have prevented investigators from studying them in great detail, and the presence of a true crater is in most cases purely a matter of conjecture. In the case, however, of such ideal

[1] Am. Journ. Sci. ser. 4, vol. xv (1903) p. 269; vol. xvi (1903) p. 107; vol. xx (1905) p. 185; and vol. xxvi (1908) p. 17.

cones as Sajama, the Payachatas, and possibly Tacora, it is hardly possible to doubt their existence without proof to the contrary, since farther north in Peru the well-known Misti (of almost identical shape) possesses a finely-developed crater.

Along the line of the Arica–La Paz section, no one of these cones is at present in a state of activity, though minor phenomena associated with waning volcanic action are constantly observed. On the sides of Mount Taapaca, for instance, near the village of Putre, hot springs still issue from the snow-covered ground, the water, which is nearly at boiling-point, being conducted into baths and used for curative purposes.

The whole coastal region, as has been already mentioned, consists of a rainless sandy desert formed by the disintegration of volcanic products, and fresh specimens of the underlying rocks can only be obtained from the cuttings made during the construction of the railway, or in the immediate vicinity of the volcanic cones. The enormous amount of volcanic material which has been spread over the surrounding country may be realized from the fact that, between the highest visible outcrop of Mesozoic strata in the Llutah Valley and the summit of Mount Taapaca, there is a difference of level amounting to over 11,000 feet.

It was found impossible, therefore, to study these vast accumulations of lava and tuff in great detail, and no attempt will be made here to deal with them otherwise than in general outline. From an examination of a number of microscopic sections, it appears that they can be resolved into three main groups, characterized by their dominant ferromagnesian mineral. Succeeding one another in the following order, they seem to obey a law of increasing basicity with decreasing age:—

(α) Acid rhyolites and rhyolitic tuffs with biotite.
(β) Trachytes or trachy-andesites with hornblende.
(γ) Andesites or basalts with pyroxenes.

It must be pointed out, however, that some of the rocks of the first group occasionally include xenoliths of more basic character, derived from earlier-formed lavas not exposed at the surface.

(α) The rhyolites and rhyolitic tuffs are chiefly characteristic of the coastal region; it is frequently impossible to say whether they have been poured out as true lavas, or represent pyroclastic deposits.

They have a rough trachytic texture, and are usually pale in colour, with a range varying from purple and pink to grey and white. They are characterized by an abundance of small quartz-crystals with bipyramidal terminations—in fact, it is scarcely possible to pick up a handful of the desert sand without noticing this feature. Clear glassy porphyritic crystals of felspar, both sanidine and plagioclase, usually occur accompanying the quartz, and biotite is the only common ferromagnesian element. The ground-mass is frequently vitreous or cryptocrystalline, and often exhibits microspherulitic structure.

These rocks are best studied along the railway, where they are well displayed between Poconchile and the 'Pampa Colorada,' and again from Central to Puquios. (Pl. IV, fig. 1.)

The following description of a few typical examples will serve to illustrate their general facies :—

(A_6) Rhyolite; quarries near Molino.

Macroscopic characters: This rock consists essentially of phenocrysts of quartz, glassy clear felspar, and black hexagonal plates of mica set in a fine-grained pink matrix.

Microscopic characters: Idiomorphic phenocrysts of quartz, sanidine, and acid plagioclase with polysynthetic twinning and occasional zonary banding. Dark-brown biotite is fairly abundant, much broken and bent, and exhibits resorption-borders. Apatite occurs sparingly, in small needles.

The ground-mass is cryptocrystalline to vitreous, with evident flow-structure. Abundant spherulitic or axiolitic growths of delicate fibres occur lining irregular cavities, the centres of which seem often to be filled by a fine quartz-mosaic or possibly tridymite.

(A_7) Rhyolite; cuttings above Poconchile.

Macroscopic characters: Similar to (A_6), but of a greyish colour and with copper-coloured mica.

Microscopic characters: Similar to (A_6); ground-mass cryptocrystalline, with obscure grains of quartz and felspar bereft of definite outlines. No flow-structure visible.

(A_{46}) Rhyolite; Kilometre 110.

Macroscopic characters: Phenocrysts of quartz, glassy clear felspar, and black mica, in a purplish-red vitreous matrix.

Microscopic characters: Idiomorphic phenocrysts of quartz, sanidine, and acid plagioclase. Biotite not very abundant, deep reddish-brown in colour, with corrosion-borders. Magnetite occurs sparingly.

The ground-mass shows marked flow-structure, and consists of brown isotropic glass alternating with cryptocrystalline bands. Microspherulitic structure is occasionally developed.

South of the railway, thousands of feet of lava and tuff, presenting a wonderful variety of colours, are again visible in the Jamiraya gorge, lying horizontally upon the steeply-dipping Jurassic shales and the granodiorite core.

In many respects, these rocks are essentially similar to those described above, but from their position are obviously of somewhat earlier date. Hornblende is occasionally met with, although biotite is still the dominant ferromagnesian mineral, and there is an abundance of quartz.

(A_{47}) Rhyolite; below Patapatani, Llutah River.

Macroscopic characters: This rock is almost identical in appearance with (A_{16}), but has a greyish colour.

Microscopic characters: Large phenocrysts of quartz occur, frequently with crystal outline, but more usually rounded by

corrosion; quartz also occurs as a secondary product, filling vesicles in the form of a mosaic. Sanidine subordinate to plagioclase, which is mostly albite and oligoclase.

Biotite is not very abundant, it is bent and broken, and there is a little green hornblende posterior to the biotite. Apatite, zircon, and magnetite occur sparingly.

The ground-mass consists of a pale brownish glass crowded with minute spherulites, which, in addition to showing black crosses between crossed nicols, can also be recognized under a high power in ordinary light.

Abundant foreign xenoliths of a more basic type, composed chiefly of plagioclase-crystals in a brownish vitreous or cryptocrystalline ground-mass, without quartz, but with abundant magnetite, occur throughout this rock.

(A_{13}) Rhyolite; Patapatani, Llutah River.

This rock underlies (A_{47}), and represents an older series.

Macroscopic characters: An even-grained, compact, grey rock, splitting easily in one direction along the lines of flow.

The phenocrysts are chiefly quartz and bronze-coloured mica without much felspar, set in a vitreous base. Numerous inclusions of clear black glass occur.

Microscopic characters: Small phenocrysts of quartz, plagioclase (chiefly albite), and biotite; the last-named is much bent, and shows parallel arrangement along the lines of flow.

Apatite occurs as inclusions in the biotite. Hornblende occurs very sparingly; it is greenish brown, and shows corrosion.

Ground-mass of pale-brown isotropic glass, including corroded patches of clear colourless glass with conspicuous flow-structure.

(β) The lavas included in the second or trachytic group are typically absent along the line of railway, but attain their maximum development in the region south of the Llutah Valley, being especially characteristic of the district of Putre, where they represent the last phase of activity of the volcanic cone of Mount Taapaca. The sheets of lava which, with interbedded tuffs, build up this huge cone have a very distinct facies, and the typical rock referred to as 'Putre trachyte' is always easily recognizable among the boulders carried down the Llutah River. It is, however, never met with on the opposite or north side of the valley, which therefore was probably in great part formed prior to the eruption. Although quartz is occasionally present, it is never so abundant as in the rhyolitic group, the most characteristic feature of the rock being the numerous large, clear, porphyritic crystals of felspar, which are set in a ground-mass of predominantly grey colour. Microscopically, a distinguishing feature is the presence of hornblende in addition to the biotite.

Associated with these hornblende-trachytes or trachyandesites occur vast thicknesses of volcanic tuffs and agglomerates, which are well displayed in the river-section between

Patapatani and Huaylas, where they form picturesque cliffs of a beautiful red or crimson colour.

Owing to the porous nature of these rocks, they have frequently become mineralized by infiltrating solutions. In one case the whole matrix of an agglomerate was found to be completely impregnated with magnetite; more usually, the change has been one of silicification, resulting in the conversion of the bulk of the rock into chalcedony or opal.

(A_{19}) Trachyte or trachy-andesite; Mount Taapaca.

Microscopic characters: Felspar in the form of large tabular phenocrysts: some sanidine, but mostly an acid plagioclase showing Carlsbad and polysynthetic twinning, with common zonary structure. Quartz is present sparingly in large phenocrysts. Hornblende is abundant in small idiomorphic crystals, with strong dark-brown to yellow pleochroism. Abundant dark-brown biotite.

The accessory minerals include sphene, sparingly in characteristic wedge-shaped crystals, with high birefringence; magnetite, apatite, and augite (represented by a few small pale-green to colourless crystals).

The ground-mass is vesicular and glassy, with microlites of felspar and hornblende, and grains of magnetite exhibiting parallel arrangement along lines of flow.

(γ) The lavas of the third or andesitic group are characteristic of the region between Titiri and the Bolivian frontier, where they have been emitted from the volcanoes of Tacora and Chupiquiña, and overlie the pale rhyolites. They are also met with as dykes cutting through the latter. One particularly good example is to be seen on the banks of the small river near Titiri, where, owing to the more rapid weathering of the porous rhyolites, the basic dyke stands out as a conspicuous wall showing well-developed transverse prismatic jointing.

These rocks, owing to their compact basaltic structure and their dark coloration, present a very distinct appearance, and are further characterized microscopically by the presence of pyroxene as the dominant ferromagnesian element.

(A_{25}) Pyroxene-andesite; Mount Tacora. (Pl. VII, fig. 4.)

Macroscopic characters: A compact, black, basaltic-looking rock, with minute laths of white felspar and occasional larger phenocrysts of pyroxene. (Specific gravity $=2{\cdot}84$.)

Microscopic characters: Plagioclase (acid labradorite) occurs in tabular or lath-shaped, square-ended, idiomorphic phenocrysts, showing Carlsbad and polysynthetic twinning, and inclusions of the ground-mass arranged in zones. Little or no decomposition is visible.

Abundant pale-green to colourless augite occurs in small idiomorphic crystals, frequently showing complicated twin intergrowths. There is also a considerable amount of rhombic

pyroxene, displaying lower interference-colours than the augite and straight extinction. The cross-sections are almost square, and the prism-faces are hardly developed.

Magnetite is abundant, especially as minute granules in the ground-mass. One or two rounded xenocrysts of hornblende occur, with strong corrosion-borders.

The ground-mass exhibits hyalopilitic structure, consisting of brown isotropic glass crowded with parallel microlites of felspar and granules of magnetite.

(ii) The Altaplanicie or High-Level Bolivian Plateau.

Between the Western and Eastern Cordilleras lies the high-level Bolivian plateau known as the Altaplanicie. Though broken up by numerous minor ranges, the general surface of the country has a mean elevation of about 13,000 feet. The drainage of nearly the whole of this vast area is effected by the Desaguadero and its tributaries. This river flows southwards from Lake Titicaca into Lake Poopoo, from which there is no visible outlet; its fall, moreover, is so slight, that in times of great rainfall the surrounding country becomes flooded for hundreds of square miles, and it is difficult to say in which direction the water is flowing. It may be spoken of, therefore, as constituting an internal system of drainage, distinct from the rivers of the Pacific and Atlantic slopes. The extreme eastern limit of the Altaplanicie, however, is drained by the river of La Paz, which cuts through the Eastern Cordillera to join the Atlantic system.

Though largely concealed by wide tracts of alluvium, the basement of the eastern part of the Altaplanicie is seen to be formed of strongly-folded Palæozoic sediments, which are overlain on the west by transgressive Cretaceous deposits; these, in turn, are covered by extensive sheets of volcanic material, which are probably of post-Miocene age. To the last-mentioned deposits I shall refer as the 'Mauri Volcanic Series,' from their extreme development in the western part of the area, which is drained by the Mauri River.

(*a*) The Mauri Volcanic Series. (Pl. IV, fig. 2.)

Having passed through the Western Cordillera and crossed the Bolivian frontier, one notes that the whole surface of the country is still continuously covered by extensive deposits of volcanic origin; and, where these are cut by river-erosion, the valleys are flanked by monotonous flat-topped hills, which impart a very peculiar and characteristic aspect to the landscape. Though apparently a plane surface, in many cases it presents examples of honeycomb weathering on an immense scale; and, crossing the hill-tops, one may wander for miles through a perfect labyrinth of natural rooms and corridors, which have an extraordinarily artificial appearance. This type of country continues down the Caño and Mauri Rivers for a distance of some 60 miles. Although these rocks

have so wide a distribution, they vary little in general composition throughout the whole area. They consist for the greater part of porous white and pinkish rhyolitic tuffs and ashes, usually containing abundant quartz-crystals, and often much included pumice, ranging from minute fragments up to blocks of considerable size. The underlying rocks, too, are frequently visible along the sides of the river-valleys, in the form of thick beds of porphyry-conglomerate, which Forbes included in the Jurassic System. No fossils were obtained, however, from these beds and, as their field-relations are usually most obscure, no exact determination can be made, though I am of opinion that they will eventually prove to be of Tertiary age.

The question of the origin of the volcanic rocks is one of considerable interest. Forbes[1] describes them as

'having been erupted through long narrow fissures or dykes, and poured out over the country either as lava, or in some cases, as light volcanic ashes emitted from the fissures, and deposited on the ground in their neighbourhood, where they have gradually consolidated into beds.'

Having spent considerable time in traversing this district, I have come to the conclusion that such a theory of fissure-eruption does not explain many of the observed phenomena. If these deposits be regarded as true igneous lavas, their acid composition would involve high viscosity; and, for this reason alone, it would be hard to account for the wide extension of individual sheets and the marked horizontality of the bedding. Moreover, anything approaching the nature of a lava-filled fissure is of rare occurrence.

The general appearance of the beds is totally unlike that of any true lava with which I am acquainted, and at once calls to mind a deposit such as the well-known trass of the Brohlthal in the Eifel district. The only explanation, therefore, which to my mind can account for their peculiar nature is that they have been formed to a large extent as subaqueous deposits—an idea also partly suggested by Forbes (*op. supra cit.* p. 25).

The eastern portion of the Altaplanicie was, in comparatively recent times, the site of a great system of lakes or inland seas (of which Lake Titicaca alone survives), and in mid-Tertiary times these probably extended far to the westward, reaching to the foot of the present Western Cordillera: being here well within the range of volcanic activity, they became gradually filled up by ashes and dust, with occasional pumiceous lavas. This hypothesis is further supported by the fact that in many localities the volcanic beds are interstratified with layers of fine gravel, which present the appearance of lacustrine deposits and occasionally yield organic remains.

A few miles below the Mauri bridge were obtained specimens of a silicified tree-trunk and a fragment of the symphysis of a mandible of *Nesodon*. The occurrence of the latter, 13,000 feet above sea-level, is of considerable interest: for, as pointed out to me by Dr. C. W. Andrews, it is almost identical in general appearance

[1] Q. J. G. S. vol. xvii (1861) p. 24.

and mode of fossilization with numerous specimens preserved in the British Museum (Natural History) from the Santa Cruz Beds of Patagonia, which are of Miocene age. A horizontal section of the silicified tree has been kindly examined for me by Miss N. Bancroft, who reports that the wood is that of a Dicotyledon and appears to agree fairly closely with one of the Lauraceæ, being very similar to *Cinnamomum glanduliferum* and also to *Nectandra* from British Guiana. According to Engler & Prantl, Brazil was one of the principal centres of distribution of the Lauraceæ, and their appearance in Bolivia would therefore not be improbable in Miocene times. It would be unsafe to base any definite conclusion as to the date of the deposit from a single specimen of this nature; but the occurrence of *Nesodon* is sufficient to prove that most of the volcanic beds of the Mauri River were formed during or subsequent to Miocene times, and, as it will be shown later that they are overlain by river-gravels containing numerous remains of Pleistocene mammalia, a sufficiently approximate estimate of their age can thus be arrived at.

These Miocene or post-Miocene volcanic rocks are occasionally found to have been penetrated by still later igneous intrusions, which occur in the form of dykes or small necks cutting through the overlying beds. In common with the sequence noted from the coastal region, these later rocks have, as a rule, a more basic composition, acid dykes being of somewhat rare occurrence.

There are only two localities, where such intrusions are met with, that are of sufficient interest to deserve mention. The first is situated on the River Caño, about a mile above its junction with the main stream. Here, pale tuffs of the Mauri Volcanic Series overlie steeply-dipping beds of porphyritic conglomerate, the latter being composed of well-rounded pebbles which consist chiefly of basic igneous rocks. In the narrow railway-cutting at this point, both are seen to be cut across and metamorphosed by a broad dyke of rhyolite, with a chilled vitreous margin and well-marked flow-structure.

The rocky outcrop of this dyke can be traced for some distance south-eastwards. On the opposite side of the river rises a rounded hill, having the appearance of a small volcanic neck, composed of a coarse porphyritic andesite, which has the following distinctive characters:—

(A_{54}) Andesite; River Caño (Bolivia). (Pl. VII, fig. 6.)

Macroscopic characters: A compact, dark reddish-brown rock, containing big porphyritic crystals of glassy clear felspar, hornblende, and augite in a microcrystalline base.

Microscopic characters: Plagioclase, near andesine or acid labradorite, occurs sparingly as large clear porphyritic phenocrysts, and abundantly as a second generation in the ground-mass. Hornblende is abundant as large idiomorphic phenocrysts of a dark brownish-green with strong pleochroism, often twinned

and showing pronounced corrosion-borders. Augite is equally abundant as large pale-green phenocrysts, with marked zonary and hour-glass structure.

The ground-mass consists of a brownish glass containing small felspar-laths, magnetite, and abundant short prisms with hexagonal cross-sections of a brown pleochroic apatite. The pleochroism appears to be due to numerous minute inclusions arranged in fine lines parallel to the *c* axis of the crystals.

Note on the zonary structure in the augite.—These crystals show a darker, more ferruginous kernel with a wide extinction-angle (about 40°) surrounded by alternating light and dark bands, with a paler margin having an extinction of about 32°. The simultaneous crystallization of the hornblende- and augite-phenocrysts probably has an intimate connexion with the colour-variation in the zones of the latter mineral. If we suppose that the commencement of growth of the hornblende occurred slightly later than that of the augite, on its separation the magma would become impoverished in iron and the composition of the next augite zone would tend to be less ferriferous and of a paler hue, while any later change of physical conditions causing partial resorption of the hornblende with liberation of iron would possibly result in the formation of a more ferriferous zone in the augite. Thus successive growth and resorption in the one mineral may be recorded in the varying colour-zones of the other.

The second locality where igneous intrusion occurs is situated a few miles up a small tributary stream which enters the Mauri River from the north, about Kilometre 250 (see map, Pl. X, fig. 2). Here, the Mauri tuffs are penetrated by a dyke of trachyte or trachy-andesite, which is of interest as showing a close similarity with the rocks of the second or trachytic group of the coastal series (see pp. 21–22).

(A_{26}) Trachy-andesite; Kilom. 250, Mauri River (Bolivia).

Macroscopic characters: A pale-grey trachytic rock, with phenocrysts of clear white felspar and smaller crystals of black hornblende and biotite.

Microscopic characters: Felspar, chiefly plagioclase near oligoclase, in large clear porphyritic crystals, with Carlsbad and albite-twinning and zonary structure. Hornblende abundant in idiomorphic crystals; strongly pleochroic, deep reddish-brown to pale yellow. Biotite dark brown, in part subsequent to the felspar-phenocrysts. Apatite occurs sparingly as small needles.

The ground-mass consists of a colourless glass, with abundant microlites of felspar, rather short and stout in shape, approaching an orthophyric type of structure. Lines of flow not evident.

(*b*) The Mesozoic and Palæozoic Rocks of the Altaplanicie and the Line of Dioritic Intrusions.

The vast covering of ashes and tuff described above gradually thins out, and disappears about 3 miles beyond the bridge over which the railway crosses the Mauri River.

Its limit is marked by an abrupt change in the nature of the landscape, the flat-topped sides of the river-valley, cut through the horizontal volcanic deposits, giving place to scarped hill-faces formed by steeply-dipping stratified rocks. Before discussing the latter in any detail, it is necessary to describe briefly the section as far east as Coniri (see map, Pl. X, fig. 2).

At the point where the Mauri tuffs are last met with appears a series of red gypsiferous sandstones, cropping out from beneath the volcanic rocks under which they dip westwards. These sandstones can be traced in a series of folds, past the village of Calacoto across the Desaguadero River to Comanche, where they are broken through by a line of dioritic intrusions. About 5 miles beyond this point they are seen to overlie, with apparent conformity, a second series of darker chocolate-coloured sandstones and conglomerates, which continue as far as Coniri, where they end abruptly along a fault-line against vertical shales and yellow sandstones of Devonian age.

This thick series is remarkable for the complete absence throughout (or, at least, extreme rarity) of any organic remains, with the exception in one or two localities of indeterminable fragments of plants and a few derived fossils in the Coniri conglomerate. In consequence, there has been considerable difference of opinion as to the correct determination of its geological age.

A. d'Orbigny colours the beds as Devonian, Carboniferous, and Trias; Forbes, comparing them with similar deposits in Europe, assigns them to the Permian or Trias; Prof. Steinmann considers them as the equivalent of his fossiliferous Cretaceous 'Puca' Sandstone of more southern localities, while many local mining experts regard them as of still later date. With the exception of D'Orbigny's classification, the general tendency has been to place all these beds in one continuous series, but the view that I have adopted since studying the country farther north is that they are divisible into two groups, which may be defined briefly as follows:—

(1) A younger, red gypsiferous sandstone and marl series of Cretaceous age, resting with pseudoconformity upon

(2) an older, chocolate-coloured sandstone and conglomerate series of probably Permian or Permo-Carboniferous age.

(1) The first group consists for the most part of brick-red and crimson sandstones containing abundant gypsum and rock-salt, variegated red and tea-green marls, and thin paper-shales, the whole series being strongly reminiscent of the British Trias and evidently formed under somewhat similar conditions.

This fact at first led me to regard Forbes's determination as the correct one; but, after working northwards through Peru, and noting

the wide Cretaceous transgression which had taken place over the older rocks, where similar beds of red sandstone are occasionally interbedded with the limestones, I came to the conclusion that the red sandstone series of Bolivia might be regarded as a shallow-water facies of the fossiliferous Cretaceous limestones of the Peruvian sierras. Probably it was deposited in an inland sea, cut off from the clear waters of the ocean and subject to intense evaporation and concentration. The presence of drifted tree-trunks in this formation further suggests the proximity of land.

After my return to England, I learnt that Prof. Steinmann had visited Corocoro, and correlated these beds with his Cretaceous 'Puca' Sandstone.

The beds, though thrown into a number of folds, have a general strike to the north-north-west; where first met with, they seem to dip about 25° westwards beneath the volcanic rocks of the Mauri River.

Though their outcrop is frequently concealed by the Pleistocene river-gravels described below, they can be followed from Calacoto southwards along the Desaguadero River past Ulloma, where they dip in an easterly direction, being folded into a broad syncline between this point and the village of Callapa. Everywhere the beds contain abundant seams of gypsum, often of considerable thickness.

In the well-known mining district of Corocoro the sandstones are richly impregnated with native copper, which occurs both in the form of large irregular masses and disseminated in minute fragments throughout the rock. Although a discussion as to its exact mode of origin cannot be attempted here, it can hardly be doubted that the presence of copper in the metallic state is due to the intrusion of the dioritic rocks.

The zone of dioritic intrusions.—The dioritic rocks appear along the line of section in the imposing peak known as Comanche Alto and the smaller foothill at its base, where they have been extensively quarried during the construction of the railway (Pl. X, fig. 1 & Pl. V). Forbes, although omitting to illustrate this line of dioritic intrusions in his transverse section, compares it with the 'plutonic intrusion' of the Western Cordillera.

In this he appears to have had little justification: for, neither in petrographical characters nor in mode of occurrence, have the two rocks anything in common. The western plutonic core, as described above (p. 17), seems to have made its way into the overlying rocks by a process of replacement rather than displacement; while the latter mode of origin is essentially the case in the present instance. The sandstone beds have here been upheaved and broken through by the diorite, and dip steeply away from it in every direction. The igneous rock, moreover, has penetrated them in the form of numerous dykes, which are not, as a rule, well developed in the case of a batholithic intrusion. The metamorphism is not great, and has resulted in little more than a hardening and bleaching of the beds along the immediate contacts.

(A_{29}) Diorite; Comanche (Bolivia). (Pl. VII, fig. 5.)

Macroscopic characters: A pale-grey holocrystalline rock of even-grained medium texture, composed of white plagioclase and dark-green hornblende, the latter frequently segregated into more basic patches. No quartz visible. It often contains abundant micaceous hæmatite, especially developed along the joint-faces.

Microscopic characters: Holocrystalline, hypidiomorphic structure. Plagioclase, chiefly andesine and acid labradorite, showing Carlsbad and polysynthetic twinning and well-marked zonary structure. The felspar is mostly fresh, but exhibits some alteration to sericite—beginning usually at the centre of the crystals. Green hornblende occurs in small well-defined crystals, with idiomorphic contours. Ilmenite altering to sphene, and a little apatite, epidote, and chlorite also are present.

(2) About 5 miles east of Comanche, the red gypsiferous sandstones and marls are seen to overlie the rocks of the second series with apparent conformity. The latter, however, I regard as forming a distinct group, the junction being one of transgressive overlap. The original dip of the older beds was probably insignificant in comparison with their present inclination, and the intense Tertiary folding, which affected both Cretaceous and older rocks alike, has enhanced the deceptiveness of this pseudoconformity.

The rocks of the older series consist of dark-red and chocolate-coloured sandstones (Pl. VI), with frequent bands of conglomerate; and, being more resistant than those of the first group, they stand out in bolder relief. They are strongly folded throughout, the western limbs of the anticlines having, as a rule, the greater inclination—in fact, in some instances, they approach a monoclinal structure, the direction of folding having been apparently towards the west. At Coniri, dipping 30° north-eastwards, they end abruptly, along a fault-line, against vertical shales and sandstones of Devonian age.

The last beds of the series exposed are coarse conglomerates, composed of big well-rounded pebbles, set in a compact reddish or green matrix impregnated with copper. The pebbles consist chiefly of olive-green and liver-coloured quartzites, yellow sandstone, vein-quartz, red crinoidal limestone apparently of Carboniferous age with poorly-preserved fossils (*Spirifer* sp., *Chonetes* sp., *Euomphalus* sp., *Rhipidomella* sp., and a small semireticulate *Productus*), white sandstone with a small species of *Orthis*, pink limestone with *Fusulina*, and dolomite with *Fenestella*. A careful search failed to reveal any trace of granitic or other igneous pebbles, as mentioned by Forbes, although they occur abundantly in the alluvial deposits of the valley. That author further describes these conglomerates [1] as comprising the lowest beds of the sequence; but it seems clear, from their easterly dip, that they must overlie a considerable

[1] Q. J. G. S. vol. xvii (1861) p. 38.

thickness of the chocolate sandstones to the westward, which for some distance dip in the same direction.

Diagrammatic geological section across the Straits of Tiquina, Lake Titicaca.

1 = Shales.
2 = Limestone with *Productus cora* and *Spirifer condor*.
3 = Limestone with *Euphemus* cf. *indicus*, *Seminula ambigua* mut., and *Spiriferina cristata*.
4 = Yellow and black shales.
5 = Red and chocolate-coloured sandstones and breccias.

My reason for regarding the sandstones and conglomerates of this series as of much earlier date than the gypsiferous Cretaceous sandstones is, that they can be traced far to the north along the west side of Lake Titicaca, where they appear to be continuous with the limestones and sandstones of Carboniferous or Permo-Carboniferous age, and are distinct from the overlying transgressive Cretaceous deposits.

(*c*) The Carboniferous or Permo-Carboniferous Rocks of the Titicaca District.

Though a few derived fossils are met with in the conglomerate-beds of Coniri, rocks which can be definitely assigned to the Carboniferous formation are nowhere visible *in situ* along the Arica–La Paz section, and as a geological description of the country would appear incomplete without some reference to this formation, a slight digression must be made to discuss its development in the region of Lake Titicaca, which lies some 30 miles away to the north. Here an excellent section is visible along the shores of the lake at the Straits of Tiquina, on the Peninsula of Copacabana and on the Island of the Sun.

The rocks, which consist of red sandstones and breccias, yellow and black shales, and grey cherty limestones, though strongly folded, failed to reveal evidence of the intense overfolding depicted by Forbes.[1]

Unfortunately, several of my notes and an excellent map of the district were, among other possessions, stolen by a boatman who transported our luggage across the lake, and consequently the section cannot be produced in the detail with which it was studied; it will serve, however, to show my interpretation of

[1] Q. J. G. S. vol. xvii (1861) p. 49, fig. 5.

the sequence and the position of the two important outcrops of limestone (see diagrammatic section, p. 30).

The Straits of Tiquina, which form a narrow passage about half a mile wide between the northern and southern portions of the lake, lie along the axis of a steeply-folded syncline of red sandstone and breccia, faulted on its eastern side against Devonian quartzites and underlain conformably on the west in the peninsula of Copacabana by yellow and black shales, which dip 60° north-north-eastwards.

The latter are succeeded by a thick outcrop of grey cherty limestone, containing numerous examples of *Euphemus*, *Spiriferina*, and *Seminula*: the last-named occur chiefly in the form of silicified casts showing the internal spires. Towards the summit of the hill above San Pedro a second and lower limestone appears, which is characterized by *Productus cora* and *Spirifer condor*. The dip here changes to a westerly direction, and the beds appear to form the summit of a normal anticline.

From this locality David Forbes obtained the series of fossils afterwards described by J. W. Salter.[1]

In addition to my own specimens, I have examined a number of Carboniferous fossils brought back from Bolivia by other travellers; these are preserved in the British Museum (Natural History), and by the kindness of the Trustees I have been enabled to incorporate them in my description of the formation. Some are of interest as coming from A. d'Orbigny's type-locality of Yarbichambi between Huarina on Lake Titicaca and La Paz; others are from Yampupata on the Copacabana peninsula, as also from Arque, a locality farther south in the Oruro district.

Most of the specimens that I have examined appear to belong to an Upper Carboniferous or Permo-Carboniferous fauna, showing affinities with types described by Chernyshev from the Urals; while a few seem more nearly related to Permian forms figured by Waagen from the Salt Range of India, and by Girty from the Guadalupian fauna of New Mexico. The evidence for this comparison, which is more fully stated below, points to the fact that the true fossiliferous Lower Carboniferous (or Avonian) of Europe is not represented, or remains undiscovered, in this region of Southern Peru and Bolivia.

Faunal List.

Spirifer condor D'Orb.
Spiriferina aff. *cristata* Schloth.
Seminula ambigua mut. (Sow.) = *S. peruviana* (D'Orb.).
Productus cora D'Orb.
Productus aff. *spinulosus* J. Sow.
Productus semireticulatus mut. Mart.
Productus antiquatus mut. Sow.
Scabriculocostate *Productus* = *Pr. inca* D'Orb.
Enteletes aff. *hemiplicata* Hall.
Rhipidomella sp.
Derbya sp.
Hustedia sp.

Euphemus cf. *indicus* Waagen.

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[1] Q. J. G. S. vol. xvii (1861) p. 64 & pl. iv.

Palæontological Notes.

Spirifer condor D'Orb. (Pl. IX, figs. 1 *a*–1 *c*.)

This species, first figured and described by A. d'Orbigny from Yarbichambi (Bolivia),[1] appears to be a late mutation of *Spirifer striatus* Sow., though sufficiently distinct from it to be retained as a separate species.

It differs from Sowerby's form, chiefly in the greater expression of certain marked features, which may be regarded as old-age characters showing an advanced stage of development.

A comparison of the two species shows that *Sp. condor* is more acuminate in shape, and possesses a broader area and more fully-developed median fold and sinus, which are strongly marked off from the lateral portions of the shell. The fold is evenly rounded, its steep sides never meeting in an angle, as is commonly the case in *Sp. striatus*. The growth-lines are very numerous and strongly marked, and, crossing the well-developed ribs, produce a characteristic lamellate surface, aptly described by Chernyshev as resembling a tiled roof (dachziegelförmige Zuwachslinien).

Spirifer condor has frequently been regarded as identical with *Sp. cameratus* Mart., but differs from it in the absence of the strongly-marked grouping of the ribs into bundles which is so characteristic of that species.[2]

A closely-related form, but also differing in the presence of marked rib-bundling, is *Sp. musakheylensis* Dav., fine examples of which are figured by Waagen[3] from the *Productus* Limestone of the Salt Range. This species agrees well with the Bolivian one in the strongly-lamellate character of the ornament and the marked development of the median fold.

Spirifer condor has also been described by Chernyshev from the '*cora*' and '*Schwagerina*' horizons (Permo-Carboniferous) of Timan and the Urals.[4]

Seminula ambigua Sow., mutation = S. peruviana (D'Orb.). (Pl. VIII, figs. 3 *a*–3 *c*.)

This species seems to be well represented, both in the Titicaca region and in other more southern localities. The specimens are well preserved, and in the silicified examples from San Pedro the internal spires are frequently visible. The shells show somewhat wide variation in shape, but the most extreme types are insensibly connected by intermediate forms, and all may be referred to the one species.

[1] 'Voyage dans l'Amérique Méridionale: Paléontologie' 1842, pp. 46–47 & pl. v, figs. 11–14.

[2] See J. Hall, 'Nat. Hist. New York: Palæontology, vol. viii, pt. 2 (1894) Introduction to the Study of Palæozoic Brachiopoda' pl. xxxii, figs. 9–15.

[3] 'Salt Range Fossils' Pal. Indica, ser. 13, vol. i (1887) p. 512 & pl. xlv.

[4] Mém. Com. Géol. Russie, vol. xvi, No. 2 (1902) pl. xii, figs. 1–2, & pl. xxxviii, figs. 1–2.

A more or less typical example is figured by A. d'Orbigny[1] under the name of *Terebratula peruviana*. The same species is again figured by Salter,[2] who refers it to *Athyris subtilita* (Hall).

The Bolivian shells, however, are of a much smaller size than Hall's species,[3] and seem to agree more closely with *Seminula subquadrata* Hall.[4] The latter species does not appear to differ to any great extent from the British *Seminula ambigua* (Sow.), of which Dr. Vaughan has shown me examples from the Scottish Coal Measures that are quite indistinguishable from my specimens, the strongly-marked growth-halts and pronounced nature of the median fold showing in general an advance on more typical Avonian forms.

PRODUCTUS CORA D'Orb.

Examples of this species are everywhere numerous in the cherty limestones around Lake Titicaca; and, as A. d'Orbigny obtained his type-specimens from this district (Yarbichambi), a further description is unnecessary.

An early mutation is well known from the Lower Carboniferous of Great Britain, where it has been used as a subzonal index (S_2) of the Avonian succession.[5]

A more advanced type, however, is the *Productus cora* from the Permo-Carboniferous *cora* horizon of the Urals,[6] which differs from the British form in its larger size and the possession of well-marked spines irregularly scattered over the surface of the shell. This old-age feature, unknown or extremely rare in the Avonian mutation, is also characteristic of the Bolivian shells, and furnishes additional evidence for regarding the limestones in which they occur as of Upper Carboniferous or Permo-Carboniferous age.

D'Orbigny's original figures[7] are very much idealized, his type-specimen being again figured in its natural state by Chernyshev.[8]

Typical spinose examples of this species also occur, though rarely, in the Upper *Productus* Limestone of the Salt Range.[9]

PRODUCTUS aff. SPINULOSUS J. Sow.

This form, which occurs in association with *Productus cora*, agrees closely with Sowerby's species in the regularly-convex ventral valve without a sinus, ornamented with irregularly-arranged, rounded, erect tubercles which bear long slender spines.[10] It is, however, slightly

[1] 'Voyage dans l'Amérique Méridionale: Paléontologie' 1842, pp. 36–37 & pl. ii, figs. 22–25.

[2] Q. J. G. S. vol. xvii (1861) pl. iv, figs. 4*a* & 4*b*.

[3] See figures, 'Nat. Hist. N. Y. Pal.' vol. viii, pt. 2 (1894) pl. xlvii, figs. 19–21.

[4] *Ibid.* figs. 7–9.

[5] A. Vaughan, 'Palæontological Sequence in the Carboniferous Limestone of the Bristol Area' Q. J. G. S. vol. lxi (1905) p. 291 & pl. xxv, figs. 4–4*b*.

[6] F. Chernyshev, Mém. Com. Géol. Russie, vol. xvi, No. 2 (1902) pl. liv.

[7] 'Voyage dans l'Amérique Méridionale: Paléontologie' 1842, pl. v, figs. 8–10

[8] Mém. Com. Géol. Russie, vol. xvi, No. 2 (1902) p. 622, fig. 69.

[9] W. Waagen, Pal. Indica, ser. 13, vol. i (1887) pl. lxvi, fig. 3.

[10] See T. Davidson, Mem. Palæont. Soc. 'British Fossil Brachiopoda' vol. ii (1858–63) pl. xxxiv, figs. 18–21.

less transverse, and in this respect resembles *Productus wallacei* Derby, figured by Chernyshev from the *cora* and *Schwagerina* horizons of the Urals.[1] A somewhat similar form, *Pr. opuntia*, has also been described by Waagen from the Salt Range.[2]

Semireticulate Productids.

If we except *Productus cora* and the 'spinulose' Productids, the remaining examples of the genus all belong to a semireticulate group, in which Dr. Vaughan suggests three distinct forms can be recognized. In the first the semireticulation is irregularly developed and the spines are numerous, in this respect approaching a scabriculate type of ornament. In addition to this character, the steep sides of the shell and its general outline make it almost impossible to separate it from a form which occurs commonly in the uppermost beds of the Avonian in the British South-Western Province, just below the Millstone Grit and also in the Middle Coal Measures. It has been termed a 'scabriculocostate' *Productus*.

The shell figured by A. d'Orbigny[3] as *Productus inca* may also be referred to this form, as it shows strong scabriculate characters, and the semireticulation, in common with his other figures, is doubtless considerably idealized.

Salter refers *Productus inca* D'Orb. to *Pr. semireticulatus* Mart., and his figure[4] possibly represents an example of this species, although it certainly, as drawn, bears no resemblance to the *Pr. inca* figured by A. d'Orbigny.

The remaining two forms Dr. Vaughan considers to represent late mutations of *Productus antiquatus* Sow. and *Pr. semireticulatus* Mart. The first shows the general shape and regular reticulation of Sowerby's species; but it exhibits a distinct senile character in the way in which the radial ribs come together beyond the reticulate portion of the shell—thus being considerably reduced in number, and leaving relatively-broad flattened spaces between them. At the points of junction the ribs frequently bear spine-bases.

The specimens that I have determined as mutations of *Pr. semireticulatus* Mart. (Pl. VIII, fig. 6) differ from the above in the irregular nature of the reticulation and in the very pronounced nodular character of the intersections between the ribs and the concentric folds, in this respect being in a more advanced stage than the typical Avonian forms and similar to those found in the Coal Measures. The fusion of the ribs to form intervening flat spaces on the skirts of the shell is also observed in this species, and suggests a gradual passage to a more highly-specialized semireticulate type with a completely-smooth margin, such as *Pr. vishnu* from the Middle *Productus* Limestone of the Salt Range.

[1] Mém. Com. Géol. Russie, vol. xvi, No. 2 (1902) pl. xxx, fig. 8 & pl. lx, figs. 19–23.

[2] Pal. Indica, ser. 13, vol. i (1887) p. 707 & pl. lxxix, figs. 1*a*–2*b*.

[3] 'Voyage dans l'Amérique Méridionale : Paléontologie' 1842, p. 5 & pl. iv, figs. 1–3.

[4] Q. J. G. S. vol. xvii (1861) pl. iv, fig. 1.

It appears doubtful whether D'Orbigny's type of *Pr. boliviensis* must rank as a separate species from the above, and little can be gleaned from his idealized drawings[1]; but, if we turn to Chernyshev's interpretation of the species as represented in the Urals, we can trace a close resemblance with the Bolivian shells. This author states that he has seen D'Orbigny's type-specimen, and, as he still retains the specific name for his Uralian examples, they evidently differ somewhat from our common British semi-reticulate forms.

The incipient smoothness of the margin of the shell and the nodular character of the semireticulation are also, apparently, features of A. d'Orbigny's species, as is shown by Chernyshev's figures.[2]

ENTELETES aff. HEMIPLICATA Hall. (Pl. VIII, figs. 2 *a*–2 *c*.)

This genus, of which the type is *Enteletes lamarcki* of Fischer de Waldheim from the Moscovian of Russia, was reintroduced by Waagen, in order to supersede the name *Syntrielasma* of Meek & Worthen.

As representative of a subfamily of the Orthidæ, it includes certain resupinate forms, which show advanced characters suggestive of a passage from the Schizophorids to the Rhynchonellids. The genus has been fully described by Waagen,[3] and it is only necessary here to restate a few of its more important features: such as, the strong plication of the valves; the presence of a thin blade-like median septum between the dental plates in the pedicle-valve; and the extreme development of the brachial 'crura.' The same author has subdivided the genus into two groups: 'Ventrisinuati' and 'Dorsosinuati'—according to the presence of the median sinus on the ventral or on the dorsal valve. Such a division, however, does not appear to be absolute, as in many examples there occurs incipient plication of the actual fold and sinus—thus reversing the conditions, and suggesting a transition from one group to the other.

The occurrence of this genus in the Carboniferous Limestone of Bolivia, represented by a single well-preserved specimen brought back by Col. Lloyd from Arque in the Oruro district, is a point of some interest, for the genus is characteristic of the Middle and Upper Coal Measures in the United States, and survives in the Lower Guadalupian fauna of New Mexico and the Permian of the Salt Range. Waagen's species from the Salt Range are almost all dorsosinuate forms,[4] and differ in their more pronounced folding from the Bolivian specimen, which bears very close resemblance to *Enteletes hemiplicata* of Hall from the Upper Coal Measures

[1] 'Voyage dans l'Amérique Méridionale: Paléontologie' 1842, pl. iv, figs. 7–9.

[2] Mém. Com. Géol. Russie, vol. xvi, No. 2 (1902) pl. xxxii, fig. 5 & pl. xxxv, fig. 3.

[3] Pal. Indica, ser. 13, vol. i (1887) p. 550.

[4] *Ibid.* pl. lvii, figs. 1–8.

of Kansas City and Winterset.[1] A form (which also appears to be an *Enteletes*) was figured by A. d'Orbigny[2] from Yarbichambi, Bolivia, under the name of *Terebratula andii*, which Waagen compares with his *Enteletes ferruginea*. This shell differs from the form here described in the much greater plication of the valves, the folds being apparently continuous to the beak.

Another Bolivian example, from the same locality, which may probably be referred here, is that figured by Salter[3] from Forbes's collection under the name of *Orthis resupinata*; the drawing appears to represent a ventral view. Dr. E. Schellwien has suggested[4] that the earliest *Enteletes* were strongly plicated, while the late Permian forms belong to a retrograde series with smooth or faintly plicated shells, though this does not seem to be the case in Waagen's strongly-folded specimens from the Salt Range. There seems, however, to be no definite reason for assigning a faintly-plicated form to a Permian horizon, as it is natural to suppose that, in the successive stages of its development, the genus attained a strongly-folded shell after passing through the intermediate stages from a normal *Schizophoria*.

Dr. G. H. Girty[5] records a number of species belonging to this genus, of which the forms most nearly related to ours come from the Hueco formation, apparently equivalent in age to the Uralian of Chernyshev.

EUPHEMUS cf. INDICUS Waagen. (Pl. VIII, fig. 5.)

This genus is one of the subdivisions of the family of *Bellerophon*, being characterized by a more or less globular or lenticular shell possessing rounded whorls without an umbilicus. The shell is thick, and covered by a variable number of spiral folds or ridges: these do not adhere firmly to it, but appear to belong to the callosity of the inner lip, being deposited on the preceding whorl by the lobe of the mantle after the manner of columellar folds. These ridges never reach as far as the outer lip of the aperture, thus leaving a portion of the shell smooth. The aperture is never expanded, and the dorsal slit-band is absent or but slightly indicated.

The genus first appears in the Silurian rocks, and attains its maximum above the Carboniferous.

Waagen, in describing a number of species from the *Productus* Limestone of the Salt Range,[6] divides them into two groups:—

[1] 'Nat. Hist. N. Y.: Palæontology' vol. viii, pt. 1 (1892) pl. vii *a*, figs. 44–52.

[2] 'Voyage dans l'Amérique Méridionale: Paléontologie' 1842, p. 45 & pl. iii, figs. 14–15.

[3] Q. J. G. S. vol. xvii (1861) pl. iv, fig. 3.

[4] 'Die Fauna der Trogkofelschichten' Abhandl. K. k. Geol. Reichsanst. vol. xvi, pt. 1 (1900) p. 4.

[5] 'The Guadalupian Fauna' Prof. Paper 58, U.S. Geol. Surv. 1908, p. 290 & pl. xxvi, figs. 1–4 *b*.

[6] Pal. Indica, ser. 13, vol. i (1887) p. 165.

a group of *Euphemus urii* Flem.,[1] in which there are numerous columellar folds projecting more or less widely in front of the mouth; and a group of *Eu. orbignyanus* Portl., with much less numerous folds, which do not project so far. The latter group is abundantly represented in the Permian of the Salt Range, and also in the Pennsylvanian of the United States. Waagen further suggests a tendency towards diminution in the number of folds concurrently with increased development.

A well-marked species occurs abundantly in the limestones of the Titicaca district, which in general form shows a certain resemblance to *Eu. indicus* of Waagen.[2] In size, however, it is somewhat smaller, and the spiral folds, which are acute and separated by flat furrows, are slightly more numerous than in Waagen's species, numbering usually ten in an adult shell. In the young shell they are still more numerous; but, as one or two die out before the rest, there is a diminution in number with increased growth. Thus the stages of ontogenetic development appear to indicate the phylogeny suggested by Waagen.

(*d*) The Devonian Rocks of the Altaplanicie.

The strongly-marked fault at Coniri, which cuts off the eastward-dipping conglomerates and sandstones mentioned above (p. 29), is bounded on the east by vertical shales, with a strike trending almost due north, succeeded by strongly-folded olive-green quartzites and yellow sandstones with occasional calcareous bands. These beds crop out in a series of rounded hills, alternating with broad alluvial plains, as far as Viacha, and can be traced far to the north through the district of Tiahuanacu to Archacachi.

Although no palæontological evidence was obtained, they were coloured by A. d'Orbigny and Forbes as Devonian, while Pissis regarded them as of Carboniferous age. That the former determination is correct is now shown by the discovery of Devonian fossils near the village of Coniri. With the exception of this one locality, the rocks appear to be, as a general rule, extremely unfossiliferous, though rolled specimens of a *Phacops* of *latifrons* type are not infrequently found among the alluvial pebbles of the plains.

Of recent years the Devonian fauna of Bolivia has been studied in some detail by various authors, including Steinmann & Ulrich (1892), Kayser (1897), Ivor Thomas (1905), and Knod (1908). The combined results obtained by these authors show that the rocks of this formation can be correlated with the Lower Devonian of North America, being divisible into two main groups:—an upper or Humapampa Sandstone, corresponding to the Hamilton Group;

[1] Mr. H. Bolton has recorded *Euphemus urii* from the basement-beds of the Bristol Coalfield, Q. J. G. S. vol. lxiii (1907) p. 463, and from the Lower Coal Measures of Vobster, *ibid.* vol. lxvii (1911) p. 338. It has also been described from the oil-shales of the Lothians, Mem. Geol. Surv. Scotl. 2nd ed. (1912) pl. i, fig. 4.

[2] Pal. Indica, ser. 13, vol. i (1887) pl. xv, fig. 2.

and a lower or 'Icla-Schiefer,' corresponding to the Helderberg Series. The further subdivisions with their characteristic fossils are shown in the accompanying table.

North America.		Bolivia.	
Hamilton Group.	Hamilton Shales.		Humapampa Sandstone.
	Marcellus Shales.	'Icla-Schiefer' with *Leptocœlia flabellites.*	*Conularia* Shales and concretionary limestones.
Upper Helderberg Series. / Oriskany Sandstone.	Corniferous Limestone.		
	Schoharie Grit.		Calcareous sandstones with *Liorhynchus bodenbenderi* and *Leptocœlia acutiplicata.*
	Caudagalli Grit.		
Lower Helderberg Group.			Sandstones with *Scaphiocœlia boliviensis.*

The fossils recorded from Coniri, though few in number, are sufficient to assign the beds to the lower part of the 'Icla-Schiefer': the upper beds of concretionary limestones and shales with *Conularia*, which are abundantly developed farther north in the Puno district, being absent or unexposed in this region.

Faunal List.

Liorhynchus bodenbenderi Kayser.
Leptocœlia acutiplicata (Conrad).
Leptocœlia flabellites (Conrad).
Scaphiocœlia boliviensis Whitfield.
Schizophoria sp.

No evidence has yet been obtained of the existence of Upper Devonian rocks postulated by Forbes.[1]

Palæontological Notes.

Liorhynchus bodenbenderi Kayser.

The shells referred to this species, though occurring chiefly in the form of casts, are almost identical in appearance with those figured by Prof. E. Kayser [2] and by Dr. Ivor Thomas.[3]

The latter author, comparing the Bolivian with the North-

[1] Q. J. G. S. vol. xvii (1861) p. 52.
[2] Zeitschr. Deutsch. Geol. Gesellsch. vol. xlix (1897) p. 292 & pl. viii, figs. 1–10.
[3] *Ibid.* vol. lvii (1905) p. 265 & pl. xiv, figs. 31–34.

American forms, states that the chief distinction lies in the more marked ribbing of the former and in the presence of a narrow groove extending from the apex of the brachial valve. As most of my specimens are either in a poor state of preservation, or in the form of casts, I am unable to express an opinion on this point, although obsolescence of the lateral ribs is to be observed in several instances.

Leptocœlia acutiplicata (Conrad). (Pl. VIII, fig. 4.)

The numerous examples of this species agree closely with the form described by Dr. Ivor Thomas.[1]

Leptocœlia flabellites (Conrad), as interpreted by Dr. Ivor Thomas.[2]

Scaphiocœlia boliviensis, Whitfield.

The genotype of this interesting shell was first described by Whitfield [3] from near Sucre in Bolivia, and appears to be characteristic of the lowest beds of the 'Icla-Schiefer,' which probably correspond to the Lower Helderberg Group.

The specimen in my collection was obtained by one of the engineers from a railway-cutting between Coniri and Viacha, but the exact locality was not recorded.[4]

(*e*) The Alluvial Deposits of the Eastern Altaplanicie.

The folded Palæozoic rocks which form the basement of the Altaplanicie disappear from view beyond the town of Viacha, and are not seen again until the eastern range, known as the 'Cordillera Real,' is reached, where they once more crop out with steep dips along the flanks of this lofty chain. The intervening country is buried beneath a thick mantle of alluvium, which forms a wide desert-plain between Viacha and the Alto de La Paz, attaining a mean altitude of nearly 13,000 feet. On the north lies Lake Titicaca and some distance away to the south Lake Poopoo, the two being connected by the Desaguadero River.

One of the chief points to be taken into consideration in discussing the origin of these alluvial deposits of the Altaplanicie is the presence at a considerably lower altitude of deep gorges, such as that of the La Paz River, cut right through the Cordillera. These, from their great depth and the hard nature of the rocks which they traverse, would appear to have been in existence at the time of maximum extension of the lake-system, and thus must have formed a natural outlet to the eastward.

The fact that there is no evidence showing that at any time the waters were diverted in this direction is probably to be explained by the supposed existence of a ridge of Palæozoic rocks running

[1] Zeitschr. Deutsch. Geol. Gesellsch. vol. lvii (1905) p. 263 & pl. xiv, figs. 36 *a–c*, 37

[2] *Ibid.* pl. xiv, figs. 35–35 *c*.

[3] Trans. Am. Inst. Min. Eng. vol. xix (1890–91) pp. 105–107 & figs. 1–4.

[4] See also R. Knod, Neues Jahrb. Beilage-Band xxv (1908) p. 555 & pl. xxix, figs. 1–5.

west of the La Paz valley parallel to the main Cordillera, comparable with the ridge which Dr. J. W. Evans has shown to form a watershed between Lake Titicaca and the valleys of Illabaya and Sorata.

Such a ridge would have divided the eastern Altaplanicie into two parts. On the west probably existed a depression of no great depth, which was levelled up by a widespread alluvial covering of gravel and marl with recent freshwater mollusca, during a long period of gradual recession of the lake-waters, and also on the southwest by a series of gravel-terraces left by the Desaguadero River as it deepened its course in the underlying Cretaceous sandstones. On the east existed a much deeper longitudinal depression, which was probably distinct from that of the lake-system, for it is extremely doubtful whether the waters of Lake Titicaca ever overstepped the intervening barrier. This eastern depression lay parallel to, and at the base of, the Cordillera; it, also, was completely filled up by a vast accumulation of alluvial detritus.

Its great depth is well exhibited in the valley of La Paz, which has been excavated by the river to a depth of over 1600 feet without reaching bed-rock. The almost perpendicular sides of the valley are composed of horizontally-bedded clays, sands, and gravel containing large boulders of granite and Palæozoic quartzite derived from the adjacent Cordillera; these deposits are, in places, highly auriferous. Near the summit, as noted by Forbes, occurs a conspicuous white band of volcanic tuff.

With regard to the mode of infilling of this deep depression, if it be assumed that a breach through the Cordillera was already in existence, as appears probable, it might be suggested that during the final stages of elevation of the range the water-supply was diminished with the extension of the glaciers; and the La Paz River was unable to excavate its bed with the rapidity necessary to keep the outlet sufficiently open to allow of the removal of the torrential or fluvioglacial deposits, which, it may be supposed, were subsequently swept down in vast quantities from the Cordillera by the melting ice at the close of the Glacial Period.

Before discussing the origin of Lake Titicaca, it is first necessary to give a brief description of the gravel-terrace deposits of the Desaguadero. This river, flowing southwards from Lake Titicaca to Lake Poopoo, crosses the line of section near the village of Calacoto, where it is joined by its main tributary, the Mauri. Between this point and the village of Callapa three distinct terraces are visible at different levels. The highest, situated some 200 feet above the present river, is well developed in the neighbourhood of Ulloma, where it is plainly seen lying horizontally on the upturned edges of red Cretaceous sandstones. It is made up of sands, clays, and coarse quartzose gravels, the last-named being often cemented into a compact siliceous conglomerate. It is highly fossiliferous in this locality, and a number of mammalian bones were obtained, all of which also occur in the Pleistocene Pampan

formation of the Argentine Republic. These were kindly identified for me by Dr. C. W. Andrews. They include the following:—

Mandible of *Mastodon (?) andium*, a very old individual, with the surface of the teeth almost completely ground down.
Small mandible, with the two last milk-teeth (mm. 4), of *Mastodon andium.*
Right and left femurs, right radius, and a number of vertebræ of *Mastodon*; small tusk of *Mastodon (?).*
Right humerus and cervical vertebra of *Scelidotherium* sp.
Right radius of a small *Megatherium*-like animal.
Claw of *Megatherium (?).*
Phalanges and metacarpal of *Parahippidium.*

This high-level terrace has a wide distribution on each side of the present river-valley, and may be regarded as having been in great part laid down under lacustrine conditions: for, at the time of its formation, most of the country lying between the existing lakes must have been continuously covered by a vast sheet of water. Owing to the continued rise of the Eastern Cordillera, the rainfall became greatly diminished, evaporation set in, and the waters gradually receded to their present limits, possibly aided in the process by slight differential earth-movements.

As the separation of the two present lakes was thus effected, the Desaguadero, which now drains the intervening country, first became confined to a definite channel. Its fall, however, must have been so slight that constant flooding of the country was inevitable, conditions which (even at the present day) are repeated on a smaller scale during any pronounced wet season.

The existence of lower terraces of more recent date may merely indicate the recurrence of marked periods of excessive rainfall, or of increased acceleration in the uplift of the country. Apart from general considerations of topography, evidence for the former wide extension of Lake Titicaca [1] during a comparatively-late period of human existence has been obtained by Señor A. Posnansky, of La Paz, during his explorations among the ruins of Tiahuanacu.

That ancient metropolis of a pre-Inca civilization, the megalithic architecture of which is superior to anything found in the country at the present day, is now situated more than 12 miles from the shores of the lake, at an altitude of about 110 feet above its mean water-level. That the waters of the lake extended to the city at the time of its occupation has been clearly proved by Señor Posnansky,[2] who has discovered among its ruins elaborately-constructed moles and artificial canals. This author has also good reasons for supposing that the huge idols, and megalithic blocks used in the construction of the buildings, were all transported to the locality by means of rafts, or balsas, on the surface of the lake.

[1] Lake Titicaca now lies between latitudes 15° 20′ and 16° 35′ S. and longitudes 70° 45′ and 72° 10′ W. It has been estimated to be about 140 miles long and 60 miles broad, and its greatest depth is said to be 1700 feet. Its elevation above sea-level is about 12,616 feet.

[2] He estimates the age of Tiahuanacu as 11,000 years, from calculations based on the astronomic orientation of the buildings.

Such a rise of water-level, amounting to over 100 feet, would cause an enormous extension of the lake; and, if we judge from details of topography, this would have been greatest in a north-and-south direction. If, then, this extension can be proved to have existed in such comparatively modern times, it is easy to picture an earlier state involving the total submergence of the country now drained by the Desaguadero.

The presence of a marine fauna in the waters of Lake Titicaca, first discovered by Alexander Agassiz in 1878, has been held by many geologists to furnish strong proof of the elevation of the Andes in recent times. The lake is regarded as having originally been formed by an arm of the sea, which was cut off and raised during the elevation of the Cordillera to its present altitude of over 12,500 feet above sea-level. To attempt to solve this question without an extensive biological knowledge of the means by which such organisms are distributed would be entirely out of place here, but since many complications have been introduced by the writings of local investigators, I cannot refrain from passing a brief criticism on one of the most extravagant of these recent theories—that of Lorenzo Sundt. This author considers that the country has undergone the following changes of level since Cretaceous times:—

Early Tertiary, (1) a rise from the sea, accompanied by great lateral pressure and folding.
Late Tertiary, (2) a depression of 6500 feet.
(3) a further rise accompanied by folding.
Post-Tertiary, (4) a depression below sea-level, with the formation of the gravels of the Ulloma district.
(5) a final uplift of 13,500 feet, *without* lateral pressure or folding.

Such a theory seems to me to be utterly untenable.

A wide transgression in Cretaceous times over a large part of the Andes is a recognized fact; but, so far as I am aware, there is no record of any marine Tertiary deposit anywhere in the Cordillera at a greater altitude than 3000 feet. The extensive horizontal sheets of volcanic ash, etc., of the Mauri Volcanic Series have been shown in the foregoing pages to be of Miocene or Pliocene age, and to contain traces of a terrestrial fauna and flora; and it is hardly possible to suppose that they have been twice depressed below sea-level, and re-elevated to 13,000 feet, without disturbance of their horizontality. Further, the high-level terrace of Ulloma contains abundant proof of a Pleistocene mammalian fauna, and it is quite inconceivable how Sundt can regard this deposit as of marine origin.

Proof of recent elevation has also been deduced from the position of Tiahuanacu. It has been urged that the present cold and barren site, at an altitude where corn cannot ripen, would never have been selected as a suitable locality for the support of a thriving population, and that therefore at the time of its existence the country must have stood at a considerably lower altitude.

I am not prepared to deny the possibility of a slight recent elevation on these grounds, though climatal changes and the former presence of the lake might have completely altered the appearance of the landscape. The amount of depression required to reproduce suitable conditions for the existence of the city would not appear to be very great, if comparison is made with the present city of La Paz. It is, however, necessary to suppose a considerable elevation since Pleistocene times, to account for the presence of a large mammalian fauna at an altitude now almost devoid of vegetation. That this elevation amounted to over 13,000 feet, as suggested by Sundt, appears to be entirely unsupported by facts. The determination of the maximum altitude at which such life could have flourished must be left in the hands of biologists, to whom we must also appeal for further light on the possibility of recent migration of marine life to the fresh waters of Lake Titicaca.

If the lake once formed an arm of the sea, its origin, according to my observations, must date at least as far back as Miocene times, during which the greater part of the elevation of the Andes probably took place. It would then have formed a lagoon between the mainland and the rising Western Cordillera, on which already a terrestrial fauna and flora were in existence. The movement appears to have been continued since Pleistocene times, and possibly within the period of human existence, though it must be pointed out that it is hard to reconcile any theory of recent elevation with the geological evidence of the former extension of the glaciers of the Cordillera in this latitude.[1]

(iii) The Eastern Cordillera and the Amazon Slopes.

(*a*) The Palæozoic Sedimentary Rocks.

The Bolivian Altaplanicie is bounded on the east by the great mountain-range usually known as the 'Cordillera Real.' Its snow-capped peaks (Illimani, Mururata, Caca-Aca or Huaina Potosi, Illampu, etc.) rise to still greater heights than those of the Western Cordillera, and are built up entirely by Palæozoic sediments with a granitic core. All traces of recent volcanic activity are completely absent.

Our line of section, as stated above (p. 5), was continued from La Paz eastwards across the Cordillera Real down to the hacienda of Mururata. A remarkably wet season at the time of our visit to this locality, with practically continuous tropical rain on the eastern slopes, made detailed work almost impossible. The description of this portion of the section is therefore necessarily somewhat incomplete, and I do not attempt to give more than a rough outline of its geological features.

[1] At the present day, the glaciers of Mount Illimani extend down to about 15,750 feet.

Leaving La Paz and ascending the valley of Chuquiagillo, renowned for its rich gold-washings, we soon leave behind the alluvial deposits of the Altaplanicie, and beds of dark slates and quartzites are met with below La Lancha. These at first dip steeply (60°) south-westwards; but, towards the summit of the pass, they are frequently seen to be much folded.

With the exception of a few obscure examples of *Leptocœlia*, no fossils were obtained. Prof. Hauthal, however, has recorded the following from the valley:—*Tentaculites* sp., *Leptocœlia flabellites*, *Orthis subcarinata*, *Orthotetes chemungensis*; and in addition a more extensive list of Devonian forms from the neighbouring peak of Chacaltaya. These rocks, which were regarded by Forbes as Silurian, have therefore now proved to be of Devonian age, being merely a continuation of those described farther west in the Coniri district. All the species recorded belong to a Lower Devonian facies.

The upper part of the Chuquiagillo Valley contains much morainic matter and shows abundant proof of recent glaciation. The rocks are smoothed, polished, and striated, presenting the typical rounded forms of roches moutonnées. Magnificent examples of rock-steps and barriers are also of frequent occurrence.

After crossing the pass of Huacuyo, one makes a steep descent down the U-shaped glaciated valley of Pongo, along the sides of which is exposed a fine section of dark slates and greywackes with an occasional band of quartzite. These beds dip almost continuously south-westwards (not eastwards, as stated by Forbes),[1] and therefore underlie the rocks on the western slopes of the range, from which they differ somewhat in general lithological character. With the exception of countless annelid-tracks, no fossils were recorded; but these slates and greywackes may safely be regarded as constituting an older series than the Devonian, and have therefore been coloured in the section (Pl. X, fig. 1) as Silurian.

Near the custom-house of Unduavi, traces of granite were met with; to the occurrence of this rock, however, reference will be made later.

Below Unduavi, the thick vegetation of the tropical forests is encountered, and to prove the geological continuity or relations of such beds as are shown in the rare outcrops at once becomes a matter of extreme difficulty.

After crossing the spur of Sillutincara, and descending the steep valley of the Chairo River, we observed a thick series of black shales in the river-bed, 1000 feet or more below the Tambo of Huancani. These beds were here found to be almost vertical, with a north-westerly strike. (Although no fossils were found in them, they appear to occupy the same position as the black shales recorded by Dr. J. W. Evans from the adjacent district of Caupolican, which contain numerous graptolites identified by Mrs. Shakespear as of Arenig age. I have also discovered similar graptolitic shales still farther north, in the Inambari district of Peru.)

[1] Q. J. G. S. vol. xvii (1861) p. 57.

From this point as far eastwards as Mururata Bridge, where they are well exposed along the river-banks, the rocks consist chiefly of dark slates and shales with a general dip south-westwards; immediately beyond Huancani, however, they are seen to be intensely contorted, and they also show signs of folding at the second and third bridges on the trail to Coroico.

In the neighbourhood of the hacienda of Mururata, the shales undergo a remarkable change of character, becoming very soft and friable, and paler in colour—such as lighter tints of grey, purple, and reddish hue, with frequently a silky sheen approaching that of a phyllite. These beds also appear to agree closely with the description given by Dr. Evans of the rocks met with in the district of Caupolican, where they were found to contain fragments of Upper Cambrian and Ordovician trilobites, identified by Mr. Philip Lake (*Peltura*, *Symphysurus*, *Trinucleus*, *Ogygia*, etc.).

Dr. Evans considers the peculiar nature of the paler shales to be due to lateritization. In the absence of direct palæontological evidence, I have coloured all the sedimentary rocks of the eastern slopes as of Silurian age; but, from comparisons with more northern districts, there is every reason to suppose that both Cambrian and Ordovician rocks are also represented.

(*b*) The Granitic Core.

Owing to the inaccessibility of the giant peaks of the Eastern Cordillera, the nature of the rocks of which they are built up has always been a matter of dispute among South American geologists.

The presence of a granitic core has, of course, invariably been recognized, from the occurrence of that rock in the form of huge boulders in the alluvial deposits of the La Paz Valley. D'Orbigny first figured Mount Illimani as a huge mass of granite; Forbes, however, denied that this was the case, and represented it as composed entirely of Palæozoic sediments. Later research has shown that neither author was strictly correct.

Sir Martin Conway has brought back gneiss and granite from near the summit of the mountain, while the slopes are known to be formed by Devonian slates and quartzites. Prof. Hauthal has also proved this to be the case for Huaina Potosi or Caca-Aca on the north and Quimsa Cruz on the south, the central core in each case being composed of a coarse granite.

The high peaks no doubt owe their existence to the resistance offered by this rock to erosive agencies, for its outcrop is not continuous along the whole summit of the range.

Crossing the pass of Huacuyo, we meet with nothing but Palæozoic sediments until Unduavi is reached, some 5000 feet down on the eastern side. Here indications are seen of granite cropping out in the immediate neighbourhood; and this is again the case near the base of the steep zigzag trail below Huancani, known as the 'Tunca Queuta' or 'Ten Turns.'

Prof. Hauthal describes the granite of the Eastern Cordillera as occurring in the form of a laccolite; but the evidence for such a mode of origin does not seem to be very strong, and its intrusion in the form of a batholith appears to be more probable. With regard to the age of the intrusion, there is a considerable difference of opinion. It was believed by Forbes to be of Middle Silurian age; but both Prof. Steinmann and Prof. Hauthal discuss the possibility of its intrusion in Tertiary times. Apart from the metamorphism of the Devonian and Silurian rocks with the production, according to Prof. Bergt of Leipzig, of andalusit-hornfels and knotenglimmerschiefer, little evidence is available. The rock differs essentially in mineralogical characters from the post-Cretaceous granodiorites of the Western Cordillera, and in my opinion there seems to be no valid reason for regarding it as other than of Palæozoic age.

Since marine Lower Carboniferous and Upper Devonian rocks appear to be absent in this district, it would appear that elevation of the land took place during those periods, and the movement was possibly accompanied by the intrusion of plutonic rock. Such a view, however, is purely conjectural, and further evidence must be sought before any exact determination of the age of the rock can be attempted.

(A_{130}) Granite; Unduavi (Bolivia).

Macroscopic characters: An even-grained white rock of granitic texture, composed essentially of clear quartz, white felspars, and black biotite.

Microscopic characters: Quartz abundant, felspars turbid, due to alteration into sericite; orthoclase and acid plagioclase with fine twin-lamellation (chiefly albite and oligoclase). Several large crystals also occur in the section, showing peculiar patchy extinction: these appear to be perthitic intergrowths of orthoclase and albite. Biotite abundant, dark reddish-brown and strongly pleochroic, much altered into green chlorite and some epidote. It contains numerous inclusions of zircon with intensely pleochroic halos, and apatite.

The rock also contains abundant fibrous aggregates of muscovite, which appear to be due to the decomposition of cordierite: some of the latter mineral remains unaltered, and exhibits brown pleochroic halos; it is also associated with brown and green spinellids.

V. General Summary and Conclusions.

The foregoing paper gives an account of the geological observations made during travels through the country comprising the frontiers of Chile with Peru and Bolivia, a summary of the results of which will serve to give a brief outline of the development of this part of the Andes during past geological ages.

In Cambrian, Ordovician, and Silurian times, the sea covered that part of the country which is now occupied by the eastern slopes of the Bolivian Cordillera. In which direction lay the land

whence the deposits laid down during these periods were derived, cannot at present be definitely stated, though the general trend of the mountain-ranges may, even at that early date, have been indicated by an elevated chain running parallel to the Pacific coast.

During early Devonian times, the sea extended over the site of the present Eastern Cordillera. Deposits with Lower Devonian fossils are known from the Matto Grosso country on the east, and, forming the flanks of the high Bolivian peaks, they continue beneath the alluvial covering of the eastern Altaplanicie as far west as the hamlet of Coniri. Owing to the absence of marine Upper Devonian and Lower Carboniferous rocks, a period of land-elevation appears to have set in at this time, and the present Eastern Cordillera was first raised above sea-level—its rise probably being accompanied by the intrusion of the granitic rock which forms its core. Though doubtless subjected to repeated oscillations, it has probably continued as a land-area down to the present day. The sea once more extended its limits, and deposits of marine Upper Carboniferous and Permo-Carboniferous age were laid down over the Altaplanicie and the Titicaca district.

With reference to the area under discussion, further historical evidence is wanting until Upper Jurassic times. Marine deposits of this age form the basement of the Western Cordillera, where they are exposed in the deeply cut river-valleys and in the Morro de Arica on the coast. Volcanic activity had already broken out, for these Upper Jurassic sediments are interbedded with thick sheets of andesite, which appear to have been formed as pillow-lava in a shallow sea not far from a coast-line.

The great development of so-called 'porphyritic conglomerate,' probably of Cretaceous or Tertiary age, indicates a further continuance of these submarine volcanic conditions. During Cretaceous times a wide transgression took place, and the sea penetrated far into the district now occupied by the western Altaplanicie. The fossiliferous limestones of the north, however, are here represented by shallow-water deposits, consisting of red sandstones and gypsiferous marls; and communication with the open sea may have been partly cut off by the accumulation of volcanic material on the west.

In Middle Tertiary times intense folding and elevation took place, and the mountain-chains of the Andes were raised high above sea-level; as most of the anticlines have their steepest limbs on the west, it would appear that the direction of the movement was from the east, or towards the Pacific. Dioritic intrusions broke through the newly-formed Cretaceous rocks along a line running through Corocoro and Comanche, and the Jurassic sediments of the coastal region were penetrated by a great batholithic mass of granodiorite, which now forms the deep-seated core of the Western Cordillera.

Volcanic activity continued with increasing force, and vast sheets of rhyolitic lavas and tuffs were poured over the western part of the country; these were succeeded by the trachytic lavas which build up the huge cone of Mount Taapaca, and the andesites

and basalts of Mount Tacora and Chupiquiña. These and other high volcanic peaks now constitute the Western Cordillera. To the east of these growing cones appears to have existed an inland sea or system of lakes, and the extensive deposits of the Mauri Volcanic Series were probably laid down in great part below water. The great lake-system, of which Lake Titicaca and Lake Poopoo are remnants, was possibly cut off as an arm of the sea during Miocene times, and gradually elevated to its present position. The whole country lay at a considerably lower altitude than it does at present, and supported an abundant mammalian fauna during Pleistocene times. The glaciers advanced down the valleys during the Glacial Period, and retreated once more to the mountain-tops, leaving behind them abundant proof of their former extension.

The uplift continued even during the time of human existence; the rainfall from the east gradually became cut off; and the lake-waters receded to their present limits.

Now we find a vast, arid, high-level plateau, the Bolivian Altaplanicie, almost devoid of vegetation and inhabited by a decadent race of Indians where once thrived a highly-cultured civilization. On the east it is cut off from the densely-forested region of the Amazon basin by the inaccessible snow-peaks of the Eastern Cordillera, formed of granite and Palæozoic sediments; on the west from the coastal deserts of the Pacific Ocean by the giant volcanic cones of the Western Cordillera.

According to Mr. McCurdy, one of the oldest European residents of Arica, a slight recent elevation of the coast is suggested by the shallowing during the last twenty years of the rocky bathing-ground, but that the movement has practically ceased is shown by the presence of pre-Spanish Indian burial-tumuli only a few feet above high-water level.

In conclusion, I have to express my best thanks, not only to Mr. W. E. Balston, who enabled me to undertake the work, but also to many friends who gave me assistance during my stay in the country; to Mr. Wynne Edwards, Sir John Jackson's representative in Chile, in charge of the construction of the Arica–La Paz Railway, and his assistant engineers, Mr. Clark, Mr. McDonald, and many others for their kind hospitality; also to Mr. Henry Schumacher, of Tacna, to whom I owe a deep debt of gratitude for placing his extensive knowledge of the country at my disposal; and, finally, to Señor Escutti Orrego, of Arica, and to Señor Don Manuel V. Ballivian, of La Paz, who gave us letters of introduction throughout Bolivia.

I also take this opportunity of acknowledging the kind help and advice which I have received from the following geologists during the working out of my results:—Dr. C. W. Andrews, Miss N. Bancroft, Dr. F. A. Bather, Dr. J. S. Flett, Mr. R. B. Newton, Prof. W. J. Sollas, Dr. A. Vaughan, and Dr. A. Smith Woodward.

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EXPLANATION OF PLATES I–X.

PLATE I.

Mount Taapaca (19,145 feet), seen from Putre.

PLATE II.

Eastern entrance to the Jamiraya Gorge, Llutah River, near Patapatani.

PLATE III.

Fig. 1. Pillow-lava, Morro de Arica (Chile).
2. Individual pillows embedded in *Posidonomya* Shales, at the same locality.

PLATE IV.

Fig. 1. Bedded rhyolites, tunnel (Kilom. 81), Arica–La Paz Railway.
2. Volcanic beds of the Mauri River (Bolivia).

PLATE V.

Intrusion of diorite through Cretaceous sandstones, Comanche (Bolivia).

PLATE VI.

Chocolate-coloured sandstones and conglomerates of Permian age, east of Comanche (Bolivia).

PLATE VII.

Fig. 1. A_{10}. Granodiorite invaded by acid magma; Llutah River, near Cata (Chile); showing hornblende (black) in process of solution by quartz, and an irregular mosaic of quartz (clear) and felspar (turbid). (In ordinary light, $\times 16{\cdot}6$ diameters.) See p. 17.
2. The same between crossed nicols, $\times 9{\cdot}3$ diameters.
3. A_2. Enstatite-andesite, pillow-lava; Morro de Arica (Chile); augite (Au), enstatite (En), and plagioclase (andesine), with polysynthetic twinning, in an opaque ground-mass composed of glass crowded with grains and skeleton-crystals of magnetite. (Between crossed nicols, $\times 8$ diameters.) See p. 11.
4. A_{25}. Augite-andesite; Mount Tacora (Chile); showing parallel arrangement of felspar-crystals (clear) with marginal zonary inclusions. Pyroxenes (tinted): augite and enstatite, in a hyalopilitic ground-mass. (In ordinary light, $\times 9{\cdot}3$ diameters.) See p. 22.
5. A_{29}. Diorite; Comanche (Bolivia); showing zonary structure of plagioclase, and small idiomorphic crystals of hornblende. (Between crossed nicols, $\times 8$ diameters.) See p. 29.
6. A_{54}. Hornblende-augite-andesite; River Cano (Bolivia); porphyritic crystals of plagioclase (Pl)—andesine with Carlsbad twinning, hornblende (Hb) twinned, and showing a resorption-border, and augite (Au) with zonary structure, in a hyalopilitic ground-mass. (Between crossed nicols, $\times 8{\cdot}6$ diameters.) See p. 25.

PLATE VIII.

(All the figures are of the natural size.)

Figs. 1 *a* & 1 *b*. *Macrocephalites* sp., Callovian; Morro de Arica, Chile. (See p. 9.)
2 *a*–2 *c*. *Enteletes* aff. *hemiplicata* Hall, Upper Carboniferous; Arque, Bolivia. (See p. 35.)
3 *a*–3 *c*. *Seminula ambigua* Sow., mut. = *S. peruviana* (D'Orb.), Upper Carboniferous; Straits of Tiquina, Bolivia. (See p. 32.)

J. A. D. Photo. Bemrose, Collo, Derby

Mount Taapaca (19,145 Feet), seen from Putre.

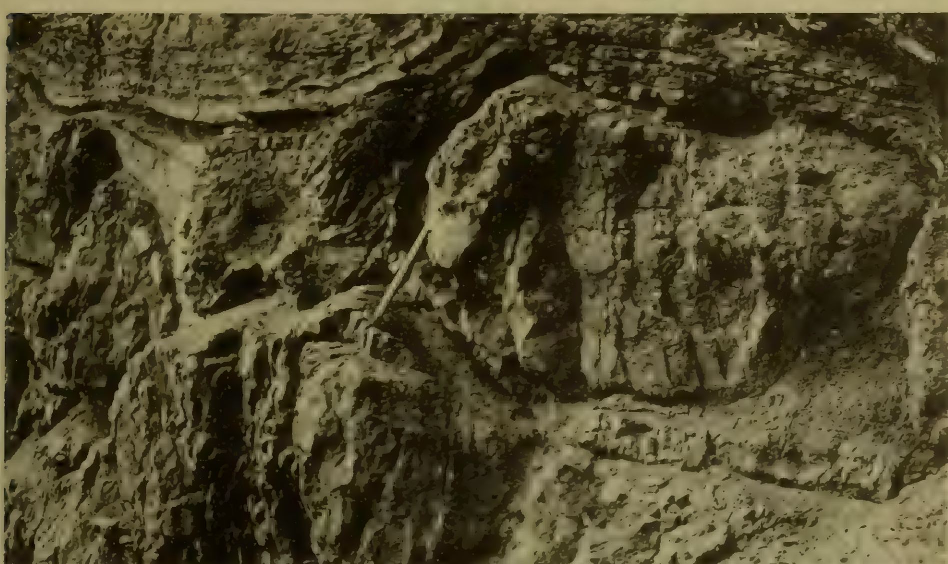
J. R. T. Photo. Bemrose, Collo., Derby.

Eastern Entrance to the Jamiraya Gorge, River Llutah, near Patapatani.

Fig. 1. — PILLOW-LAVA, Morro de Arica (Chile).

J. A. D. Photo.

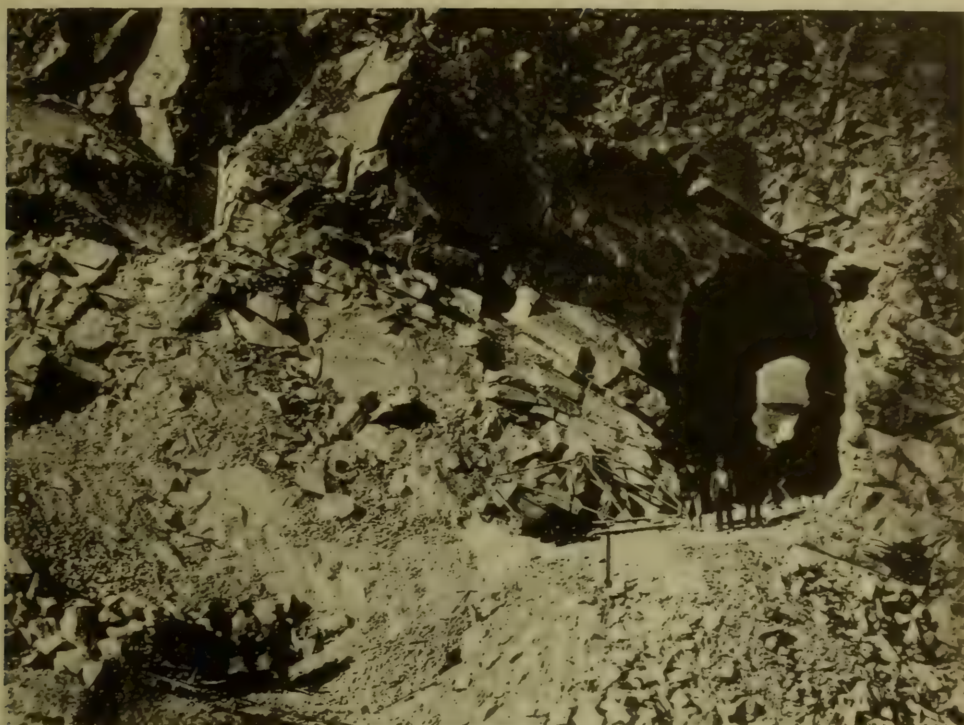
Fig. 2. — Individual Pillows embedded in *Posidonomya* Shales Morro de Arica (Chile).



J. A. D. Photo.

Bemrose, Collo, Derby

Fig. 1.— BEDDED RHYOLITES. Tunnel, Kil: 81 (Arica-La Paz Railway).



H.T. Photo.

Fig. 2.— VOLCANIC BEDS of the Mauri River (Bolivia).

J.A.D. Photo.

Bemrose. Collo, Derby.

J. A. D. Photo.

Bemrose, Collo., Derby

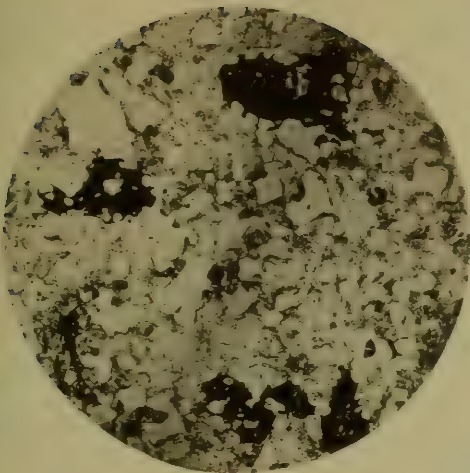
INTRUSION OF DIORITE THROUGH CRETACEOUS SANDSTONES, COMANCHE (BOLIVIA).

J.A.D. Photo.

Bemrose, Collo. Derby.

Chocolate-coloured Sandstones and Conglomerates
of Permian Age, east of Comanche (Bolivia).

1.



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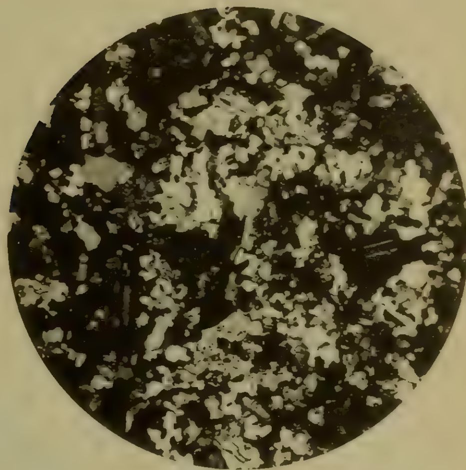

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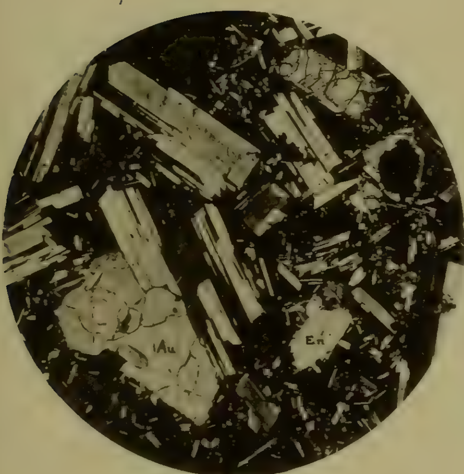

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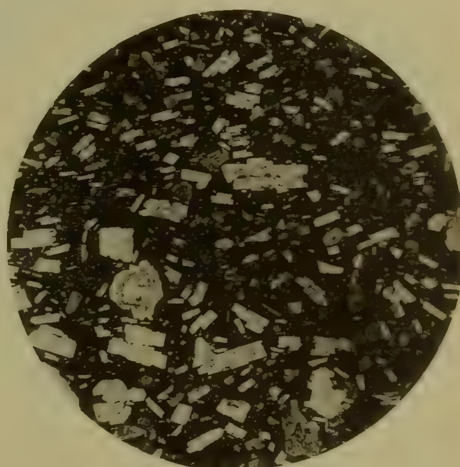

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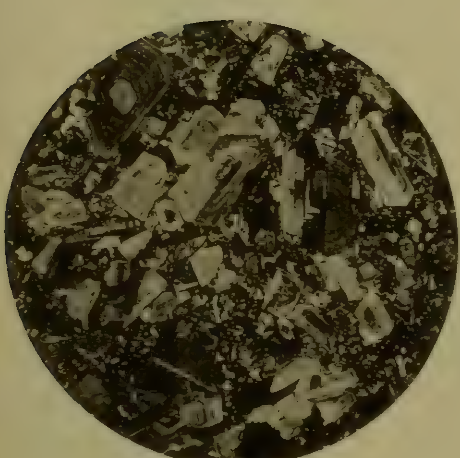
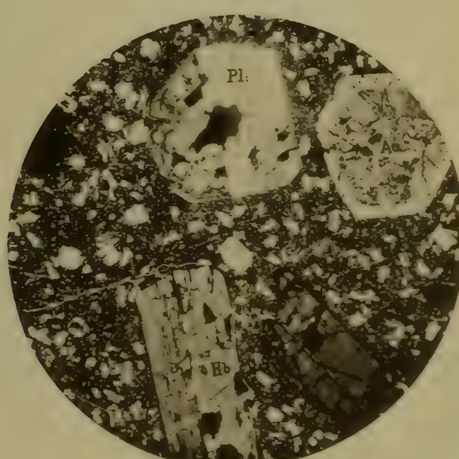


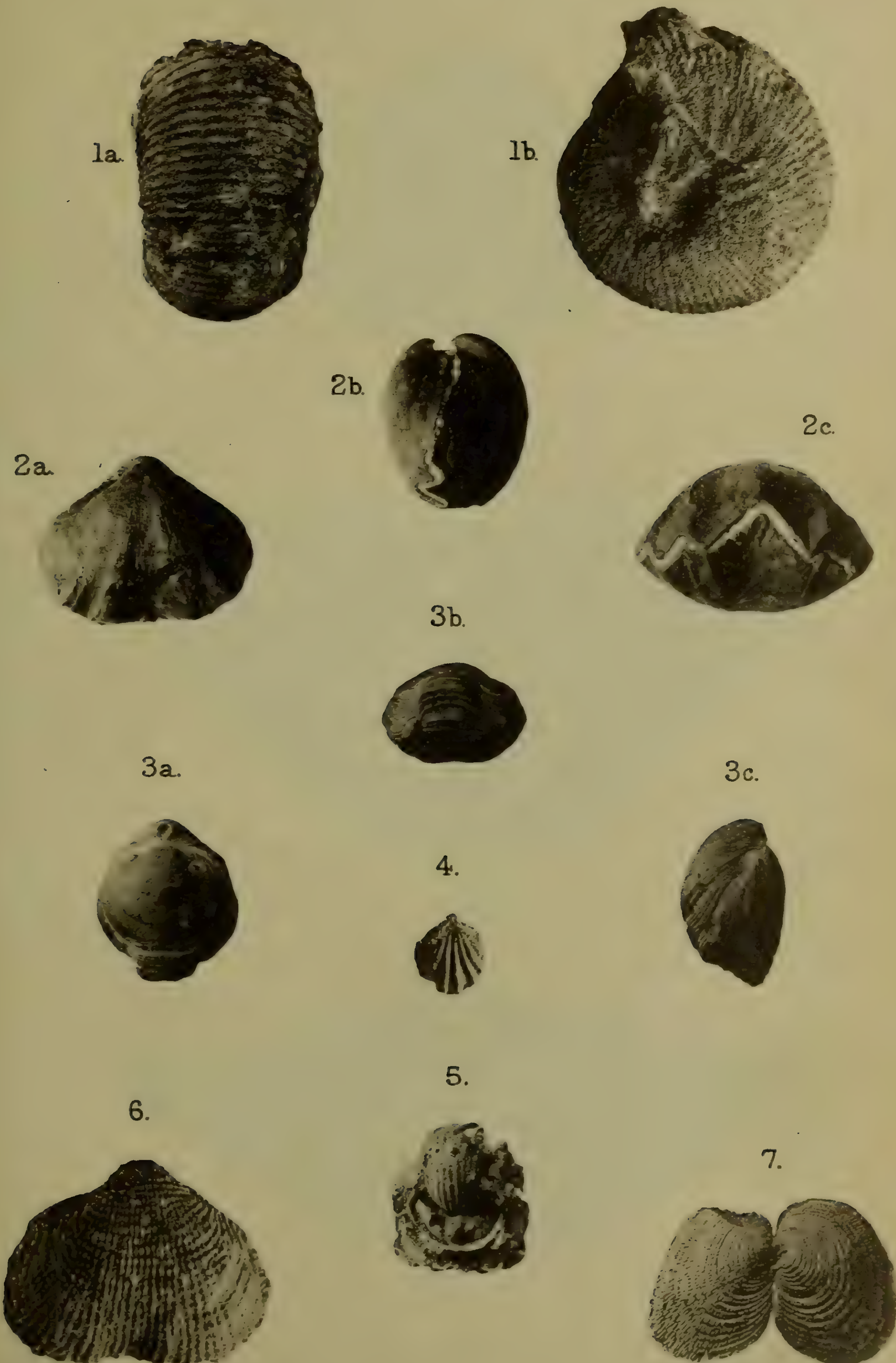
6.



J. A. D. Photomicro.

Bemrose, Collo., Derby

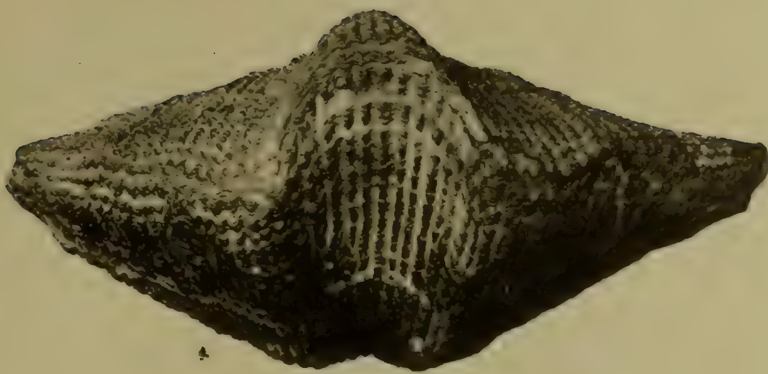
IGNEOUS ROCKS FROM THE ANDES (ARICA-LA PAZ SECTION).



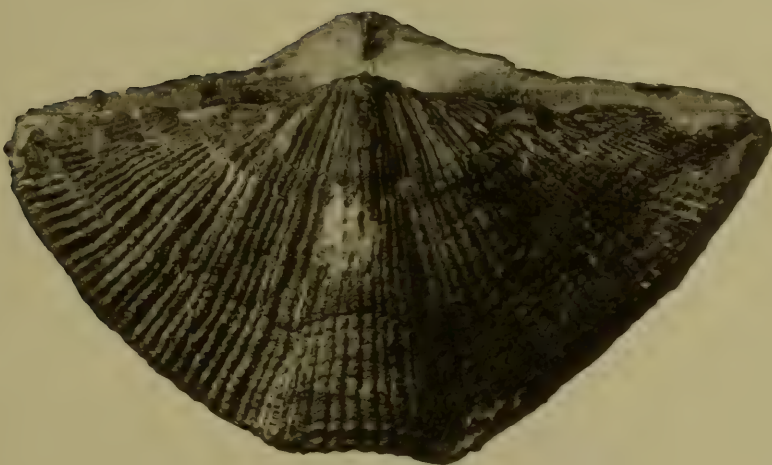
J.A.D. Photo. Bemrose, Collo., Derby.

FOSSILS FROM THE ANDES (ARICA-LA PAZ SECTION).

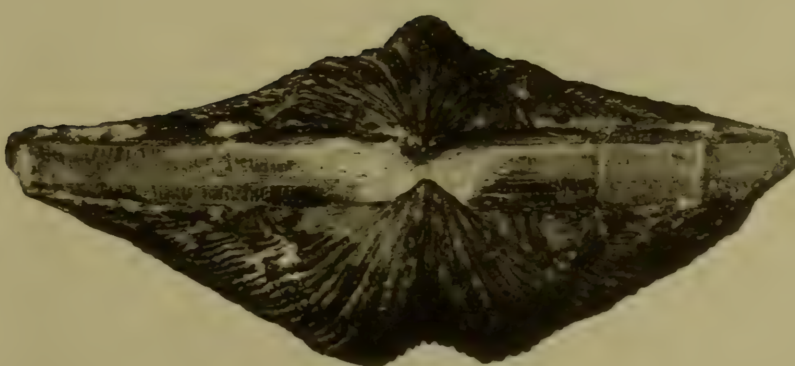
1a.



1b.



1c.



J. A. D. Photo

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FOSSILS FROM THE ANDES (ARICA-LA PAZ SECTION).

c. Vol. LXX, Pl. X.

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Fig. 1. — GEOLOGICAL SECTION THROUGH THE ANDES FROM ARICA (CHILE) TO THE BOLIVIAN "YUNGAS."

Fig. 2. — SKETCH-MAP OF THE COUNTRY BETWEEN ARICA ON THE PACIFIC COAST OF CHILE AND THE BOLIVIAN "YUNGAS." — SCALE 1:1,000,000.

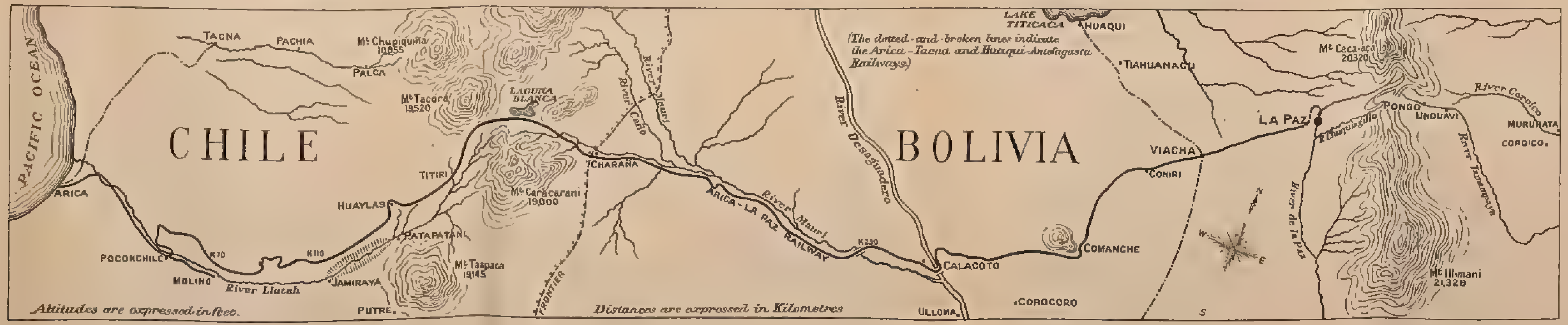

Fig. 4. *Leptocœlia acutiplicata* (Conrad), Devonian; Coniri, Bolivia. (See p. 39.)

5. *Euphemus* cf. *indicus* Waagen, Upper Carboniferous; San Pedro, peninsula of Copacabana, Bolivia. (See p. 36.)

6. *Productus semireticulatus* Mart., Upper Carboniferous; Yampupata, peninsula of Copacabana, Bolivia. (See p. 34.)

7. *Posidonomya escuttiana*, sp. nov., Oxfordian; Morro de Arica, Chile. (See p. 9.)

PLATE IX.

(All the figures are of the natural size.)

Figs. 1 *a*–1 *c*. *Spirifer condor* D'Orb., Upper Carboniferous; Yarbichambi, Bolivia. (See p. 32.)

PLATE X.

Fig. 1. Geological section through the Andes, from Arica (Chile) to the Bolivian 'Yungas.' Scales:—Horizontal, 1 : 500,000; vertical, 1 : 100,000.

2. Sketch-map of the country between Arica on the Pacific coast of Chile and the Bolivian 'Yungas,' on the scale of 1 : 1,000,000.

DISCUSSION.

The PRESIDENT (Dr. A. STRAHAN) desired to remind the Meeting of the great obligation under which they, as geologists, had been placed by the liberality of Mr. W. E. Balston. Mr. Balston had not only defrayed the cost of the expedition, but had been fortunate in his choice of so competent a geologist. The Fellows had heard an able account of the geology of an inhospitable region, and had had the opportunity of examining an admirable collection of specimens; but they had not been told of the great personal risk and extreme hardships under which the work had been carried out.

Prof. SOLLAS remarked that Mr. Balston, knowing that new railways were in course of construction in Peru, had conceived the happy idea of sending out an expedition to rescue for Science such organic remains as might be revealed in the railway-cuttings, and of applying the information which these cuttings afforded to the interpretation of the structure of the country. The Author had been invited to undertake the work on Mr. Balston's behalf, and had laboured enthusiastically for two years at the task, which was one that demanded no common powers for its accomplishment. It had not been his good fortune to discover new and strange forms of life; but he had made the best use of his opportunities, and had thrown additional light on the structure of one of the most interesting regions in the world, already rendered famous by the studies of such distinguished observers as A. d'Orbigny and David Forbes.

Dr. J. W. EVANS remarked that the Author had two great advantages over his predecessors just mentioned, whose route he had followed. He had had the benefit of the sections exposed by the

railway works, and the period which had elapsed since Forbes visited the country had witnessed the development of microscopical petrology. Of these advantages the Author appeared to have availed himself to the fullest extent.

The speaker shared the belief which the Author had expressed as to the former greater area of Lake Titicaca. He had traversed plains to the north of the lake which bore the appearance of having been recently covered by a shallow extension of its waters. He could not, however, agree with the Author that the granite of the Eastern Cordillera was probably of Carboniferous age—where he had seen it in the Tipuani Valley, it showed no signs of alteration by pressure; while the fact that an outlier of Carboniferous rocks occurred in a sharp synclinal fold near Nube on the Rio Kaka, a little to the east of the Cordillera, indicated that the rocks were subjected to powerful folding movements after Carboniferous times.

Dr. A. Vaughan joined in complimenting the Author upon his most interesting paper, and testified to the very great labour entailed in the examination of so large a collection and to the wide knowledge of every branch of geology which it demanded. In view of the fact that here, as in other parts of South America, the stratified series represented almost entirely the deposits formed during the great transgressions, the speaker asked whether the age of the Devonian rocks, in the section just described, was the same as that of the Argentine Devonian (the rocks described by Dr. Ivor Thomas); and, furthermore, what was the evidence that this date was Lower Devonian rather than Hercynian: that was, transitional between Lower and Middle Devonian?

Dr. L. L. Fermor said that, in the transcontinental and Yukon-Alaska excursions of the recent International Geological Congress, he had had several opportunities of examining the granodiorites of the Canadian section of the Cordilleran ranges, and had become interested in Prof. Daly's views on the magmatic stoping and assimilation of the intruded rocks by the granodiorites of Canada. He drew attention to the distinction that the Author had made between the modes of intrusion of the granodiorites and diorites mentioned in his paper. The granodiorites had reached their present position by replacement, and the diorites by displacement, of the associated rocks. Intrusion by replacement seemed, to the speaker, to necessitate incorporation of the replaced rock in the intruding magma. He asked the Author what evidence he had of the assimilation of the invaded rocks by the granodiorites, and whether he considered that the acid character of the granodiorite (when compared with the diorite) could be explained on that basis.

Mr. R. B. Newton referred to some brachiopod remains collected some years ago by Sir Martin Conway while crossing from Mount Milluni to the Huaina-Potosi Mine, at an elevation of 16,500 feet. In reporting upon these specimens, the speaker mentioned the occurrence of *Anoplotheca flabellites* as a characteristic Lower Devonian form, known also from the Oriskany Sandstone of the United States, and from rocks of similar age in South America,

the Falkland Islands, and South Africa.[1] Such evidence favoured the Lower Devonian age of the rocks described by the Author as containing this organism, and thus confirmed the previous researches of Dr. Ulrich on the geology of this part of South America.[2]

Mr. A. Beeby Thompson asked the Author whether, in his examination of the Lake Titicaca area, he had discovered indications of petroleum. Several years ago a prospecting party sank some boreholes a few miles away from the north-western shore of the lake near Pirin, and it was said that at depths up to 800 feet oil of a specific gravity of ·840 was struck. It was known that petroleum occurred in the Tertiary rocks of Northern Peru, and now important detailed geological studies were being made of a large area on the eastern slopes of the Cordillera in the province of Santa Cruz (Bolivia), where exudations of oil from beds of supposed Jurassic and Cretaceous age had been long known.

The Author, in reply, stated that the chief source of petroleum was in the north of Peru; possibly some of the coal-bearing shales of the south might be oil-bearing, but he was not aware that they were worked for this product. With regard to Dr. Evans's statement that the Bolivian granite showed no pressure-phenomena, he wished to point out that Sir Martin Conway had recorded gneissose structure in the granite of Mount Illimani. In forming an opinion as to the date of the intrusion, the possibility of its Palæozoic age merited further consideration, as the absence of Upper Devonian and Lower Carboniferous deposits in the area suggested a period of continental elevation at that time. In reply to Dr. Vaughan, he mentioned that several authors had published tables correlating the Devonian fossils of South America with those of the United States, and, applying these tables to the fossils that he had found near Coniri, it was clearly shown that the few forms recorded were from a Lower Devonian horizon. In conclusion, he wished to add that, owing to the kind hospitality of Mr. Wynne-Edwards and his assistant engineers, the conditions of travel over this part of the route had not been quite so arduous as some of the previous speakers had suggested. In thanking the Society for the kind reception given to his paper, he also wished to express his deep sense of gratitude to Mr. Balston for enabling him to undertake the work.

[1] See Appendix to Sir Martin Conway's 'Bolivian Andes' 1901, p. 386.

[2] Neues Jahrb. Beilage-Band viii (1892) p. 116.

2. *On the* Fossil Flora *of the* Kent Coalfield.

By E. A. Newell Arber, M.A., Sc.D., F.L.S., F.G.S., Trinity College, Cambridge, University Demonstrator in Palæobotany. (Read December 3rd, 1913.)

[Plates XI–XIII.]

Contents.

I. Introductory.

In the present paper I give the results of an examination of the fossil floras of the cores of ten further borings in the Coal Measures of the central, northern, and eastern portions of the Kent coalfield, which have been completed during the last seven years. As a rule, plant-remains proved to be abundant in these cores, and they have furnished invaluable evidence as to the geological structure of the coalfield. The whole of these new borings penetrated much deeper into the Coal Measures than those initiated at an earlier period in Kent, and thus the evidence of the fossil floras has proved to be much more complete than in the case of the cores already recorded. In several instances the borings proved the entire thickness of the Coal Measures, as developed in those particular areas, and in one locality as much as 2705 feet of measures were proved.

One boring, Barfreston, where +2103 feet of Coal Measures were proved, lies in the central area, and so does the Tilmanstone sinking, from which a few plants were also obtained. Next, we have a group of six borings in the northern region, including Goodnestone (with +1718 feet of Coal Measures), Woodnesborough

(1549 feet), Mattice Hill (1076 feet), Trapham (1651 feet), Walmestone (1201 feet), and Stodmarsh (1075 feet). Lastly, there are three borings in a more easterly direction, Maydensole (+2565 feet), Ripple (2287 feet), and Oxney (2705 feet). The fossil plants which I have collected, as the result of a careful examination of the whole of these borings, form the subject of the present paper.

With regard to previous records from the Kent coalfield, it will suffice to recall the initial determinations made by my friend Prof. Zeiller[1] in 1892 and 1894, and my previous paper[2] in this Journal in 1909. Since then I have recorded[3] two particularly interesting genera, new to Britain, and some of the fossil seeds of the coalfield are discussed and figured in 'A Revision of the Seed Impressions of the British Coal Measures,' which has recently appeared in the 'Annals of Botany.'[4]

The question of the palæobotanical horizons represented in Kent, which it was one of the main objects of this work to consider, may be more appropriately dealt with at the conclusion of the paper. It may, however, suffice to remark here, that, in addition to the Transition Coal Measures previously recorded, evidence has so far been found of the presence of only one other horizon, the Middle Coal Measures, and that there are good reasons for the belief that these two horizons alone are represented in the Kent coalfield.

I would here also express my indebtedness to the officials of the Companies owning the borings concerned, and particularly to Mr. Arthur Burr and Dr. Malcolm Burr, for their constant courtesy, and for the kind way in which they have always facilitated my work in Kent.

II. The Barfreston Boring.[5]
(Lat. 51° 12′ N., long. 1° 14′ E.)

A boring close to Barfreston Church penetrated 2103 feet into the Coal Measures, and finished in these beds. The flora of the higher 1614 feet indicates that the horizon of these measures is the Transition Series. As regards the lower +489 feet, there is some uncertainty as to the horizon, although these beds probably belong to the Middle Coal Measures. The Transition Coal-Measure flora proved to be rich in species and varied. In all, thirty-four species have been determined from the higher, and eight species from the lower horizon.

[1] Zeiller (1892) & (1894). For full references, see Bibliography, § XV, p. 80.
[2] Arber (1909). [3] Arber (1912). [4] Arber (1914).
[5] Through the kindness of Prof. W. Boyd Dawkins, F.R.S., I have been enabled to examine a number of specimens containing plant-remains from the Ropersole boring, at depths varying between 1847 and 2021 feet from the surface. These specimens are in the Manchester Museum. The only species that I could determine, however, were *Neuropteris scheuchzeri* Hoffm., *N. tenuifolia* (Schl.), and *Cornucarpus acutus* (L. & H.): the horizon of the beds is thus unknown.

Transition Coal Measure Flora of Barfreston.

Species.	Frequency. × = rare. ×× = frequent. ××× = abundant.
EQUISETALES.	
Calamites ramosus Artis	×
C. suckowi (?) Brongn.	×
C. cf. *C. cisti* Brongn.	×
Dictyocalamites burri Arber[1]	×
Annularia stellata (Schl.)	××
A. sphenophylloides (Zenk.)	×××
Calamostachys tuberculata (Sternb.)	×
SPHENOPHYLLALES.	
Sphenophyllum cuneifolium (Sternb.)	××
PTERIDOSPERMEÆ and FILICALES.	
Sphenopteris neuropteroides (Boul.)	××
S. schillingsi (?) Andrä	×
S. (Renaultia) sp.	×
Mariopteris muricata var. *nervosa* (Brongn.)	×××
M. latifolia (Brongn.)	×
Alethopteris lonchitica (Schl.)	×
A. serli (Brongn.)	×
Neuropteris flexuosa Sternb.	×
N. obliqua (Brongn.)	×××
N. tenuifolia (Schloth.)	×××
N. rarinervis Bunb.	×××
N. scheuchzeri Hoffm.	×××
N. cf. *N. (Cyclopteris) fimbriata* Lesq.	×
Odontopteris lindleyana Sternb.	×
Pecopteris miltoni (Art.)	×
P. crenulata Brongn.	×
P. (Dactylotheca) plumosa (Art.)	×
Eremopteris artemisiæfolia (Sternb.)	××
Cornucarpus acutus (L. & H.)[2]	××
LYCOPODIALES.	
Lepidodendron lycopodioides Sternb.	×
L. dichotomum Sternb.	×
Lepidophyllum lanceolatum L. & H.	××
Lepidostrobus variabilis L. & H.	×
CORDAITALES.	
Cordaites borassifolius (Sternb.)	××
C. principalis ? (Germ.)	×
CYCADOPHYTA.	
Pterophyllum sp.[3]	×

[1] Arber (1912). [2] Arber (1914). [3] Arber (1912).

The number of specimens obtained from the Middle Coal Measures was too few to indicate which were the more abundant species.

Middle Coal Measure Flora of Barfreston.

EQUISETALES.

Calamocladus equisetiformis (Schloth.).
Annularia radiata (Brongn.).

PTERIDOSPERMEÆ and FILICALES.

Sphenopteris obtusiloba (?) Brongn.
S. (Renaultia) sp.
Neuropteris obliqua (Brongn.).
N. tenuifolia (Schloth.).
Pecopteris miltoni (Artis).

CORDAITALES.

Cordaites borassifolius (Sternb.).

All the Middle Coal Measure records are common plants, but there are several from the Transition Measures of more particular interest, in addition to the exceptional specimens of *Dictyocalamites burri* Arber and *Pterophyllum* sp., already recorded.[1] *Mariopteris latifolia* Brongn. (Pl. XII, fig. 4, see p. 71) and *Neuropteris (Cyclopteris) fimbriata* Lesq., have not been previously found on this horizon in Britain. *Pecopteris crenulata* Brongn. (Pl. XI, fig. 3, see p. 73) has hitherto been only known with us to occur but rarely in the Upper Coal Measures.

III. THE TILMANSTONE SINKING.
(Lat. 51° 13′ N., long. 1° 16′ E.)

In November 1912, when the shafts of Tilmanstone Colliery had entered the Coal Measures, the following plants were obtained from the highest beds of the measures penetrated by these sinkings:—

Neuropteris obliqua (Brongn.).
Alethopteris lonchitica (Schl.).
Pecopteris miltoni (Art.).
Pecopteris sp.
Lepidodendron lycopodioides Sternb.
Lepidophyllum sp.
Lepidostrobus sp.

None of these plants are indicative of one particular horizon; but, since the same flora is also found in the highest beds of the Barfreston boring, I have little doubt that the measures at Tilmanstone belong to the Transition Coal Measures.

IV. THE GOODNESTONE BORING.
(Lat. 51° 14′ N., long. 1° 14′ E.)

This boring, near the village of Goodnestone, proved 1718 feet of measures, of which I assign the upper 312 feet or thereabouts to the Transition Coal Measures, and the lower +1406 feet to the Middle Coal Measures, in which the boring ended. A fair number of fossil plants, though not as a rule well preserved, were obtained from the higher beds; but the lower were exceptionally barren.

[1] Arber (1912).

Transition Coal Measure Flora of Goodnestone.

The flora of this horizon was very scanty. The following were the only species determined :—

Calamites cf. *C. cisti* Brongn.
Neuropteris obliqua (Brongn.).
Cornucarpus acutus (L. & H.).
Lepidodendron lycopodioides (?) Sternb.
Cordaites principalis (Germar).

Neuropteris obliqua (Brongn.) is particularly abundant. All these plants, except *Lepidodendron lycopodioides* Sternb., have been recorded from the Transition Coal Measures of the Waldershare boring,[1] and that species is known from the same horizon at Shakespeare Cliff, Dover.[2]

The flora of the lower horizon is more varied. The following is a list of the twenty species determined :—

Middle Coal Measure Flora of Goodnestone.

Species.	Frequency. × = rare. × × = frequent. × × × = abundant.
EQUISETALES.	
Calamites suckowi Brongn.	×
C. cisti Brongn.	× ×
C. ramosus (?) Art.	×
Annularia sphenophylloides (Zenker)	× ×
SPHENOPHYLLALES.	
Sphenophyllum cuneifolium (Sternb.)	×
PTERIDOSPERMEÆ and FILICALES.	
Sphenopteris schillingsi Andrä	×
Neuropteris scheuchzeri Hoffm.	× × ×
N. obliqua (Brongn.)	× × ×
N. tenuifolia (Schloth.)	× × ×
N. heterophylla Brongn.	× ×
Pecopteris arborescens ? (Schloth.)	×
Dictyopteris münsteri (Eichw.)	×
Eremopteris artemisiæfolia (Sternb.)	×
Cornucarpus acutus (L. & H.)	×
Mariopteris muricata var. *nervosa* (Brongn.)	× ×
Trigonocarpus sp.	×
LYCOPODIALES.	
Lepidodendron lycopodioides (?) Sternb.	×
Lepidophyllum lanceolatum L. & H.	× ×
Lepidostrobus variabilis L. & H.	× ×
CORDAITALES.	
Cordaites principalis (Germar)	× ×
C. borassifolius ? (Sternb.)	×

[1] Arber (1909). [2] Zeiller (1892).

Of the foregoing species the most remarkable is the doubtful record of *Pecopteris arborescens* (Schloth.), see p. 73, Pl. XI, figs. 2 & 7, which has hitherto been regarded as confined to the Upper Coal Measures.

V. The Woodnesborough Boring.
(Lat. 51° 15′ N., long. 1° 17′ E.)

A boring to the south-west of Woodnesborough, not very far from Sandwich, penetrated the entire thickness of the Coal Measures in this district, and ended in the Carboniferous Limestone. The whole of the 1549 feet of measures proved by this boring belong to the Middle Coal Measures. The plant-remains, however, were not particularly abundant, and were often badly preserved, though thirty-two species were determined.

Middle Coal Measure Flora of Woodnesborough.

Species.	Frequency. × = rare. × × = frequent. × × × = abundant.
Equisetales.	
Calamites cisti Brongn.	×
C. ramosus Art.	×
Calamocladus grandis ? (Sternb.)	×
C. longifolius (Sternb.)	×
C. equisetiformis (Schl.)	×
Annularia sphenophylloides (Zenker)	×
A. radiata (Brongn.)	×
Calamostachys longifolia Weiss	×
Sphenophyllales.	
Sphenophyllum cuneifolium (Sternb.)	×
S. cuneifolium var. *saxifragæfolium* Sternb.	×
Pteridospermeæ and Filicales.	
Neuropteris scheuchzeri Hoffm.	× ×
N. obliqua (Brongn.)	× × ×
N. heterophylla Brongn.	×
N. tenuifolia (Schloth.)	× ×
N. ovata Hoffm.	×
Dictyopteris münsteri (Eichw.)	×
Sphenopteris cf. *S. laurenti* Andrä	×
S. obtusiloba Brongn.	×
S. (Renaultia) schatzlarensis Stur	×

Middle Coal Measure Flora of Woodnesborough *(cont.)*. Species.	Frequency. × = rare. × × = frequent. × × × = abundant.
Pteridospermeæ and Filicales (*cont.*).	
Eremopteris artemisiæfolia (Sternb.)	×
Cornucarpus acutus (L. & H.)	×
Pecopteris miltoni (Art.)	× ×
P. (Dactylotheca) plumosa (Art.)	×
Mariopteris muricata (Schloth.)	×
Lycopodiales.	
Lepidodendron lycopodioides (?) Sternb.	×
Sigillaria tessellata (Steinh.)	×
Asolanus camptotænia Wood	×
Lepidophyllum minus Goode	×
Lepidostrobus variabilis L. & H.	×
Cordaitales.	
Cordaites borassifolius (Sternb.)	× × ×
C. principalis ? (Germ.)	×
Semina incertæ sedis.	
Samaropsis meachemi (Kidst.)	×
S. fluitans (Daws.)	×

Of the foregoing records, *Neuropteris ovata* Hoffm. had not been previously found below the Transition Coal Measures. Here it occurs near the top of the Middle Coal Measures.

Samaropsis meachemi (Kidst.) is a rare seed, only known from the Middle Coal Measures in a few localities.

VI. The Mattice Hill Boring.
(Lat. 51° 15′ N., long. 1° 20′ E.)

A boring at Mattice Hill, midway between Sandwich and Worth, and close to the railway, proved 1076 feet of Coal Measures before entering the Carboniferous Limestone. The beds penetrated consisted chiefly of shales, which were exceptionally rich in well-preserved fossil plants. Further, owing to the extremely large size of the cores, which in some cases exceeded 30 cm. in diameter, many excellent specimens were obtained, and this boring has so far proved to be the richest in fossil plants that has as yet been put down in Kent. No less than forty species have been determined from these cores, and these indicate unmistakably that the whole of the Measures penetrated here belong to the Middle Coal Measures.

Middle Coal Measure Flora of Mattice Hill.

Species.	Frequency. × = rare. × × = frequent. × × × = abundant.
EQUISETALES.	
Calamites ramosus Art.	×
C. cisti Brongn.	× ×
C. suckowi Brongn.	× ×
C. varians Sternb.	×
C. gœpperti Ett.	×
Calamocladus equisetiformis (Schloth.)	× × ×
C. longifolius (Sternb.)	×
Annularia sphenophylloides (Zenker)	×
A. radiata (Brongn.)	× ×
A. galioides (L. & H.)	×
Calamostachys germanica Weiss	× ×
C. longifolia Weiss	×
SPHENOPHYLLALES.	
Sphenophyllum cuneifolium (Sternb.)	× ×
S. myriophyllum Crép.	×
PTERIDOSPERMEÆ and FILICALES.	
Neuropteris scheuchzeri Hoffm.	×
N. obliqua (Brongn.)	× × ×
N. acuminata ? (Schl.)	×
N. tenuifolia (Schloth.)	× × ×
N. gigantea ? (Sternb.)	×
Dictyopteris münsteri (Eichw.)	× ×
Alethopteris decurrens (Art.)	×
Sphenopteris obtusiloba Brongn.	×
Mariopteris muricata (Schloth.)	× × ×
Pecopteris crenulata Brongn.	×
P. miltoni (Art.)	× ×
SEMINA.	
Cardiocarpus gutbieri Gein.	×
Platyspermum rugosum Arber	×
LYCOPODIALES.	
Lepidodendron ophiurus Brongn.	×
Lepidophloios laricinus Sternb.	× ×
L. acerosus ? (L. & H.)	×
Sigillaria ovata Sauv.	× ×
S. tessellata (Steinh.)	×
S. elongata Brongn.	×
Bothrodendron punctatum (L. & H.)	×
Lepidophyllum lanceolatum L. & H.	×
L. minus Goode	×
CORDAITALES.	
Cordaites borassifolius (Sternb.)	× × ×
Cordaicarpus cordai Gein.	×
Cordaicladus approximatus Ren.	×
Cordaicladus sp. nov.	×

VII. The Trapham (Wingham) Boring.
(Lat. 51° 16′ N., long. 1° 12′ E.)

A boring at Trapham, near Wingham, penetrated 1651 feet of Coal Measures before passing into the Carboniferous Limestone. The whole of the measures of this boring appear to belong to the Middle Coal Measures. The following sixteen species of fossil plants were obtained from this boring, which did not prove to be very prolific of specimens; nor were these, as a rule, well preserved.

Middle Coal Measure Flora of Wingham.

Species.	Frequency. × = rare. ×× = frequent. ××× = abundant.
Equisetales.	
Annularia radiata (Brongn.)	××
Sphenophyllales.	
Sphenophyllum cuneifolium (Sternb.)	×
Pteridospermeæ and Filicales.	
Sphenopteris obtusiloba Brongn.	×
Neuropteris scheuchzeri Hoffm.	×
N. tenuifolia (Schloth.)	××
N. obliqua (Brongn.)	×××
Alethopteris lonchitica (Schl.)	×
Pecopteris miltoni (Art.)	×
P. (Dactylotheca) plumosa? (Art.)	×
Mariopteris muricata (Schloth.)	×
Eremopteris artemisiæfolia (Sternb.)	×
Cornucarpus acutus (L. & H.)	×
Lycopodiales.	
Lepidophyllum lanceolatum L. & H.	××
Sigillaria elongata Brongn.	×
Cordaitales.	
Dorycordaites palmæformis (Gœpp.)	××
Cordaites borassifolius (Sternb.)	×××

VIII. The Walmestone Boring.
(Lat. 51° 17′ N., long. 1° 14′ E.)

A boring put down at Walmestone, north of Wingham, proved 1201 feet of Coal Measures, and then passed into the Carboniferous Limestone. The flora was found to be large and varied (thirty-three species), considering the comparative shortness of the core.

Middle Coal Measure Flora of Walmestone.

Species.	Frequency. × = rare. ×× = frequent. ××× = abundant.
EQUISETALES.	
Calamites undulatus Sternb.	×
C. ramosus Art.	××
C. cisti Brongn.	××
C. varians Sternb.	×
Annularia sphenophylloides (Zenker)	×
A. radiata (Brongn.)	×
Calamocladus grandis (Sternb.)	×
C. longifolius (Sternb.)	×
Calamostachys sp.	×
Palæostachya sp.	×
SPHENOPHYLLALES.	
Sphenophyllum cuneifolium (Sternb.)	××
S. myriophyllum Crép.	×
Sphenophyllostachys sp.	×
PTERIDOSPERMEÆ and FILICALES.	
Sphenopteris obtusiloba Brongn.	×
S. (Renaultia) schatzlarensis (Stur)	×
Neuropteris tenuifolia (Schloth.)	×××
N. obliqua (Brongn.)	×××
N. scheuchzeri Hoffm.	×
N. gigantea (Sternb.)	×
Dictyopteris sp.	×
Alethopteris valida Boul.	×
Lonchopteris rugosa Brongn.	××
Pecopteris miltoni (Art.)	×
Mariopteris muricata (Schloth.)	×
Eremopteris artemisiæfolia (Sternb.)	×
Odontopteris sp.	×
Trigonocarpus sp.	×
Samaropsis sp.	×
LYCOPODIALES.	
Lepidodendron lycopodioides Sternb.	×
L. ophiurus Brongn.	×
L. obovatum Sternb.	×
Sigillaria rugosa Brongn.?	×
S. lævigata Brongn.	×
S. ovata Sauv.	×
Lepidophyllum intermedium L. & H.	×
L. lanceolatum L. & H.	×
Lepidostrobus variabilis L. & H.	×
CORDAITALES.	
Cordaites borassifolius (Sternb.)	××
C. principalis (Germ.)	×
Dorycordaites sp.	×
Cordaites (Artisia) sp.	×
Cordaicarpus cordai Gein.	×

IX. The Stodmarsh Boring.
(Lat. 51° 17′ N., long. 1° 10′ E.)

In another boring put down at Stodmarsh, near Sturry, 1075 feet of Coal Measures were penetrated, and the Carboniferous Limestone below was also proved here. Plant-remains were fairly abundant and well preserved. The following twenty-five species from the Stodmarsh boring constitute a typical Middle Coal Measure flora:—

Middle Coal Measure Flora of Stodmarsh.

Species.	Frequency. × = rare. ×× = frequent. ××× = abundant.
Equisetales.	
Calamites cisti Brongn.	×
C. suckowi Brongn.	×
C. varians Sternb.	×
Calamocladus equisetiformis (Schl.)	×
C. charæformis (Sternb.)	×
Annularia radiata (Brongn.)	××
Calamostachys germanica Weiss	×
Sphenophyllales.	
Sphenophyllum cuneifolium (Sternb.)	×
Pteridospermeæ and Filicales.	
Sphenopteris obtusiloba Brongn.	×
S. (Renaultia) schatzlarensis ? (Stur)	×
Neuropteris scheuchzeri Hoffm.	×
N. obliqua (Brongn.)...	×××
N. tenuifolia (Schloth.)	××
N. gigantea (Sternb.)	×
Pecopteris miltoni (Art.) ?	×
Lonchopteris eschweileriana Andrä	×
Lycopodiales.	
Lepidodendron lycopodioides Sternb.	×
L. ophiurus Brongn.	×
L. dichotomum (Sternb.)	×
Lepidostrobus variabilis L. & H.	×
Lepidophyllum minus Goode	×
Cordaitales.	
Cordaites borassifolius (Sternb.)	××
C. principalis (Germar)	×
Cordaicarpus areolatus ? (Boul.)	×
Semina incertæ sedis.	
Radiospermum perpusillum (Lesq.)	×

X. The Maydensole Boring.
(Lat. 51° 10′ N., long. 1° 18′ E.)

A boring at Maydensole Farm, near West Langdon, penetrated to a depth of 2565 feet in the Coal Measures, without proving the entire thickness of the measures as there developed. The higher portion of the beds passed through (about 1156 feet) appears to belong to the Transition Coal Measures. The lower beds, about 1409 feet, are attributed to the Middle Coal Measures. The floras of both horizons are comparatively poor, fifteen species being identified from the higher and ten from the lower horizon.

Transition Coal Measure Flora of Maydensole.

Species.	Frequency. × = rare. ×× = frequent. ××× = abundant.
Equisetales.	
Calamites suckowi Brongn.	×
Annularia radiata (Brongn.)	×××
A. sphenophylloides (Zenker)	×
Sphenophyllales.	
Sphenophyllum cuneifolium (Sternb.)	×
Pteridospermeæ and Filicales.	
Neuropteris scheuchzeri Hoffm.	×××
N. obliqua (Brongn.)	×
N. rarinervis Bunb.	××
N. flexuosa Sternb.	×
N. tenuifolia (Schloth.)	×
Pecopteris miltoni (Artis)	×××
Mariopteris muricata (Schloth.)	××
Eremopteris artemisiæfolia (Sternb.)	×
Cornucarpus acutus (L. & H.)	×
Lycopodiales.	
Lepidodendron lycopodioides Sternb.	×
Lepidophyllum lanceolatum L. & H.	×

Middle Coal Measure Flora of Maydensole.

Species.	Frequency. × = rare. ×× = frequent. ××× = abundant.
EQUISETALES.	
Calamites undulatus (?) Sternb.	×
Annularia sphenophylloides (Zenker)	×
SPHENOPHYLLALES.	
Sphenophyllostachys (?) sp.	×
PTERIDOSPERMEÆ and FILICALES.	
Neuropteris scheuchzeri Hoffm.	××
N. tenuifolia (Schloth.)	×
N. obliqua (Brongn.)	×××
Alethopteris serli (Brongn.)	×
LYCOPODIALES.	
Lepidophyllum minus Goode	××
Lepidostrobus variabilis L. & H.	×
CORDAITALES.	
Cordaites borassifolius (Sternb.)	×
Dorycordaites palmæformis (Gœpp.)	×

XI. THE RIPPLE BORING.
(Lat. 51° 12′ N., long. 1° 21′ E.)

A boring at Ripple penetrated 2287 feet of Coal-Measures, and also proved the Carboniferous Limestone below.

The Transition Coal Measures here appear to be 518 feet thick.

Transition Coal Measure Flora of Ripple.

Species.	Frequency. × = rare. ×× = frequent. ××× = abundant.
EQUISETALES.	
Annularia radiata (Brongn.)	×
SPHENOPHYLLALES.	
Sphenophyllum cuneifolium (Sternb.)	×
PTERIDOSPERMEÆ and FILICALES.	
Neuropteris scheuchzeri Hoffm.	×××
N. obliqua (Brongn.)	×
N. tenuifolia (Schloth.)	×
Pecopteris miltoni (Art.)	×××
P. (Dactylotheca) plumosa (Art.) var. *dentata* (Brongn.)	×
Cornucarpus acutus (L. & H.)	×
LYCOPODIALES.	
Lepidophyllum lanceolatum L. & H.	×

and the Middle Coal Measures 1769 feet in thickness. The flora of the Transition Measures proved to be very scanty and badly preserved, only nine species being determined.

The number of species (25) obtained from the Middle Coal Measures was larger, although this flora, as a whole, was again comparatively poor.

Middle Coal Measure Flora of Ripple.

Species.	Frequency. × = rare. ×× = frequent. ××× = abundant.
EQUISETALES.	
Calamites cisti Brongn.	×
C. varians Sternb.	×
Annularia radiata (Brongn.)	×××
A. sphenophylloides (Zenker)	×
A. galioides (L. & H.)	×
Calamocladus equisetiformis (Schloth.)	××
C. charæformis (Sternb.)	×
SPHENOPHYLLALES.	
Sphenophyllum cuneifolium (Sternb.), var. *saxifragæfolium* Sternb.	×
PTERIDOSPERMEÆ and FILICALES.	
Neuropteris scheuchzeri Hoffm.	×
N. tenuifolia (Schloth.)	×××
N. obliqua (Brongn.)	××
Alethopteris decurrens (Art.)	×
Mariopteris muricata (Schloth.)	×××
Pecopteris miltoni (Art.)	×
Eremopteris artemisiæfolia (Sternb.)	×××
Cornucarpus acutus (L. & H.)	×××
LYCOPODIALES.	
Lepidodendron lycopodioides Sternb.	×
L. ophiurus Brongn.	×
L. dichotomum Sternb.	×
Lepidophyllum lanceolatum L. & H.	×
Lepidostrobus variabilis L. & H.	×
CORDAITALES.	
Cordaites principalis? (Germ.)	×
C. borassifolius (Sternb.)	××
Dorycordaites palmæformis (Gœpp.)	×
Cordaianthus pitcairniæ (L. & H.)	×

XII. The Oxney Boring.
(Lat. 51° 10′ N., long. 1° 21′ E.)

A boring, near Oxney Court, proved 2705 feet of Coal Measures, and then passed into the Carboniferous Limestone. The higher portion of the measures (about 778 feet, but the exact amount is uncertain) probably ought to be referred to the Transition Coal Measures, on the evidence of the fossil plants. The Middle Coal Measures are estimated at 1927 feet in thickness. The floras of both horizons are representative, nineteen species having been determined from the Transition, and forty-four species from the Middle Coal Measures.

Transition Coal Measure Flora of Oxney.

Species.	Frequency. × = rare. ×× = frequent. ××× = abundant.
Equisetales.	
Calamites ramosus Art.	×
Annularia sphenophylloides (Zenker)	××
Sphenophyllales.	
Sphenophyllum cuneifolium (Sternb.)	×
Pteridospermeæ and Filicales.	
Sphenopteris obtusiloba Brongn.	×
S. (Oligocarpia) brongniarti? (Stur)	×
Neuropteris scheuchzeri Hoffm.	×××
N. rarinervis Bunb.	×
Odontopteris lindleyana Sternb.	×
Pecopteris miltoni (Art.)	×××
Mariopteris muricata (Schloth.)	×
Cornucarpus acutus (L. & H.)	×
Lycopodiales.	
Lepidodendron dichotomum Sternb.	×
L. lycopodioides (?) Sternb.	×
Sigillaria ovata Sauv.	×
Lepidophloios acerosus (L. & H.)	×
Lepidophyllum lanceolatum L. & H.	×
L. minus Goode	×
Lepidostrobus variabilis L. & H.	×
Cordaitales.	
Cordaites borassifolius (Sternb.)	×

Middle Coal Measure Flora of Oxney.

Species.	Frequency. × = rare. ×× = frequent. ××× = abundant.
EQUISETALES.	
Calamites undulatus Sternb.	×
C. cisti (?) Brongn.	×
C. ramosus Art.	×
Annularia sphenophylloides (Zenker)	×
A. radiata (Brongn.)	×
A. galioides (L. & H.)	×
Calamocladus equisetiformis (Schloth.)	×
SPHENOPHYLLALES.	
Sphenophyllum cuneifolium (Sternb.)	×
S. myriophyllum Crép.	××
PTERIDOSPERMEÆ and FILICALES.	
Sphenopteris cf. *S. (Renaultia) chærophylloides* (Brongn.)	×
S. cf. *S. coralloides* Gutbier	×
S. obtusiloba Brongn.	×
Neuropteris scheuchzeri Hoffm.	×××
N. schlehani Stur	×
N. obliqua Brongn.	×××
N. tenuifolia (Schloth.)	××
N. gigantea (Sternb.)	××
Odontopteris lindleyana Sternb.	×
O. britannica Gutbier	×
Pecopteris miltoni (Art.)	×
P. crenulata (?) Brongn.	×
P. (Dactylotheca) plumosa ? (Art.)	×
Mariopteris muricata (Schloth.)	××
Eremopteris artemisiæfolia (Sternb.)	××
Cornucarpus acutus (L. & H.)	××
Alethopteris davreuxi ? (Brongn.)	×
Lonchopteris (?) sp.	×
SEMINA INCERTÆ SEDIS.	
Platyspermum elongatum ? (Kidst.)[1]	×
Samarospermum moravicum (Helmh.)[2]	×
Samaropsis fluitans (Dawson)	×
Radiospermum sp.	×
LYCOPODIALES.	
Lepidodendron lycopodioides Sternb.	×
L. obovatum Sternb.	×
Lepidophloios laricinus (?) Sternb.	×
Lepidophyllum minus Goode	×
L. lanceolatum L. & H.	×

[1] See Arber (1914). [2] *Id.*

Middle Coal Measure Flora of Oxney (*cont.*). Species.	Frequency. × = rare. ×× = frequent. ××× = abundant.
Lycopodiales (*cont.*).	
Lepidostrobus variabilis L. & H.	×
Sigillaria scutellata Brongn.	×
S. elongata (?) Brongn.	×
S. principis Weiss	×
Cordaitales.	
Cordaites borassifolius (Sternb.)	×××
C. principalis ? (Germ.)	×
Dorycordaites palmæformis (Gœpp.)	×
Cordaianthus pitcairniæ (L. & H.)	×
C. volkmanni (Ett.)	×
Cordaicarpus cordai (Gein.)	×

XIII. Remarks on the Figured Specimens.

A few of the more interesting specimens from the ten new borings in Kent are figured in Pls. XI–XIII, either on account of their rarity, or because of the horizon at which they there occur. The great majority of the other species recorded are well-known fossils, which have been frequently figured in various memoirs.

SPHENOPHYLLALES.

SPHENOPHYLLUM Brongniart, 1828.

'Prodrome d'une Histoire des Végétaux Fossiles' p. 68.

Sphenophyllum myriophyllum Crép. (Pl. XII, fig. 1.)

1880. *Sphenophyllum myriophyllum* Crépin, Bull. Soc. Roy. Bot. Belg. (C. R.) vol. xix, pt. 2, p. 25.
1886–88. *Sphenophyllum myriophyllum* Zeiller, 'Flore Fossile du Bassin Houiller de Valenciennes' p. 422 & pl. lxi, fig. 7; also pl. lxii, figs. 2–4.

This species is only known from the Middle Coal Measures, with the exception of a single record from the Lower Coal Measures of Scotland. The specimen figured in Pl. XII, fig. 1, shows three stems or branches of different sizes, all exhibiting the characteristic leaf-segments attached at the nodes.

SPHENOPTERIS Brongniart, 1822.

'Sur la Classification & la Distribution des Végétaux Fossiles' Mém. Mus. Hist. Nat. vol. viii, p. 233.

1. Sphenopteris schillingsi Andrä. (Pl. XIII, fig. 4.)

1865. *Sphenopteris schillingsii* Andrä, 'Vorweltliche Pflanzen' p. 22 & pl. vii, fig. 1.
1886–88. *Sphenopteris schillingsi* Zeiller, 'Flore Fossilé du Bassin Houiller de Valenciennes' p. 72 & pl. ii, fig. 3.
1913. *Sphenopteris schillingsi* Goode, Q.J.G.S. vol. lxix, p. 264 & pl. xxx, fig. 2.

This is a rare British plant, somewhat similar in habit to *S. obtusiloba* Brongn. and *S. neuropteroides* (Boul.), but differing from both in the pinnules being larger, more contracted at their base, and in the rachis being slenderer and non-striated.

2. Sphenopteris (Renaultia) schatzlarensis (Stur). (Pl. XII, fig. 5.)

1885. *Calymmotheca schatzlarensis* Stur, 'Farne der Carbon-Flora der Schatzlarer Schichten' Abhandl. K.k. Geol. Reichsanst. vol. xi, pt. 1, p. 265 & pl. xxxviii, figs. 1–2.
1910. *Sphenopteris (Renaultia) schatzlarensis* Renier, 'Documents pour l'Étude de la Paléontologie du Terrain Houiller' p. 19 & pl. lxiii.

This plant has a wide range, from the Lower to the Transition Coal Measures. It appears to be particularly abundant in the Middle Coal Measures of Kent.

MARIOPTERIS Zeiller, 1879.

Bull. Soc. Géol. France, ser. 3, vol. vii, p. 92.

Mariopteris latifolia (Brongn.). (Pl. XII, fig. 4.)

1829. *Sphenopteris latifolia* Brongniart, 'Histoire des Végétaux Fossiles' vol. i, p. 205 & pl. lvii, figs. 1–5.
1886–88. *Mariopteris latifolia* Zeiller, 'Flore Fossile du Bassin Houiller de Valenciennes' p. 161 & pl. xvii, figs. 1–2; also pl. xviii, fig. 1.

This species is widely distributed vertically, and is of fairly common occurrence in Britain, although it has been but rarely figured. With the specimen figured here may be closely compared the very nearly allied species *M. sphenopteroides* (Lesq.).

NEUROPTERIS Brongniart, 1822.

'Sur la Classification & la Distribution des Végétaux Fossiles' Mém. Mus. Hist. Nat. vol. viii, p. 233.

Neuropteris ovata Hoffm. (Pl. XI, fig. 6.)

1826. *Neuropteris ovata* Hoffmann, in Keferstein's 'Teutschland Geognostisch & Geologisch Dargestellt' vol. iv, pp. 158–59 & pl. i *b*, figs. 5–7.
1888. *Neuropteris ovata* Kidston, Trans. Roy. Soc. Edin. vol. xxxiii, p. 359 & pl. xxii, fig. 1.
1912. *Neuropteris ovata* Arber, Phil. Trans. Roy. Soc. ser. B, vol. ccii, p. 247 & pl. ii, fig. 9.

This plant occurs in the Upper Coal Measures, and is particularly

abundant in the Transition Coal Measures. The figured specimen from Kent is the first record from the Middle Coal Measures. In these specimens the pinnules are rather smaller than those of the fronds previously figured, but the nervation appears to me to be identical.

DICTYOPTERIS Gutbier, 1835.

'Abdrücke & Versteinerungen des Zwickauer Schwarzkohlengebirges' p. 62.

DICTYOPTERIS MÜNSTERI (Eichwald). (Pl. XI, fig. 4.)

1840. *Odontopteris münsteri* Eichwald, 'Urwelt Russlands' pt. i, p. 87 & pl. iii, fig. 2.
1886–88. *Dictyopteris münsteri* Zeiller, 'Flore Fossile du Bassin Houiller de Valenciennes' p. 294 & pl. xlix, figs. 1–5.
1888. *Dictyopteris münsteri* Kidston, Trans. Roy. Soc. Edin. vol. xxxiii, p. 361 & pl. xxi, fig. 6.

Dictyopteris münsteri is a characteristic plant in the Middle Coal Measures of Kent. In other coalfields it also occurs in the Transition and Upper Coal Measures. This species is a homœomorph of *Neuropteris heterophylla* Brongn., from which, however, it is easily distinguished by the reticulate nervation.

ODONTOPTERIS Brongniart, 1822.

'Sur la Classification & la Distribution des Végétaux Fossiles' Mém. Mus. Hist. Nat. vol. viii, p. 234.

ODONTOPTERIS BRITANNICA Gutb. (Pl. XIII, fig. 5.)

1835–36. *Odontopteris britannica* Gutbier, 'Abdrücke & Versteinerungen des Zwickauer Schwarzkohlengebirges' p. 68 & pl. ix, figs. 8–11.
1855. *Odontopteris britannica* Geinitz, 'Versteinerungen der Steinkohlenformation in Sachsen' p. 21 & pl. xxvi, figs. 8–11.
1869. *Odontopteris (Callopteris) britannica* Weiss, 'Fossile Flora der Jüngsten Steinkohle & des Rothliegenden' p. 45 & pl. i, fig. 2.

This is a very rare and but little-understood species, of which there are only three British records from the Middle and Lower Coal Measures. It closely resembles certain species of *Neuropteris*, especially *N. obliqua* Brongn., the chief distinctions being that some of the lower nerves arise direct from the rachis, and that the pinnules are attached by their whole base.

LONCHOPTERIS Brongniart, 1828.

'Prodrome d'une Histoire des Végétaux Fossiles' p. 59.

LONCHOPTERIS ESCHWEILERIANA Andrä. (Pl. XI, fig. 1.)

1865. *Lonchopteris eschweileriana* Andrä, 'Vorweltliche Pflanzen' p. 8 & pl. iii, fig. 1.
1886–88. *Lonchopteris eschweileriana* Zeiller, 'Flore Fossile du Bassin Houiller de Valenciennes' p. 246 & pl. xxxix, fig. 1.

This is a very rare plant in the British Coal Measures, there

being only two records—one from the Middle Coal Measures of Yorkshire, and the other from the Lower Coal Measures of Lanarkshire. The two fragments of pinnæ, figured in Pl. XI, fig. 1, are much narrower in proportion to their length than in Andrä's type, and agree more closely with the specimen figured by Prof. Zeiller. In the venation, however, and especially in the loose nature of the lateral nervation and the comparative fewness of the anastomoses, the Kent specimen appears to agree closely with the Westphalian type.

PECOPTERIS Brongniart, 1822.

'Sur la Classification & la Distribution des Végétaux Fossiles' Mém. Mus. Hist. Nat. vol. viii, p. 233.

1. Pecopteris arborescens? (Schloth.). (Pl. XI, figs. 2 & 7.)

1820. *Filicites arborescens* Schlotheim, 'Petrefacten-Kunde' p. 404.
1833–34. *Pecopteris arborescens* Brongniart, 'Histoire des Végétaux Fossiles' vol. i, p. 310 & pl. cii; also pl. ciii, figs. 2–3.
1890. *Pecopteris (Asterotheca) arborescens* Zeiller, 'Bassin Houiller & Permien d'Autun & d'Épinac' fasc. ii, pt. 1, p. 43 & pl. viii, fig. 1.

This species has hitherto been generally regarded as confined to the Upper Coal Measures. In a previous paper[1] I doubtfully referred to it a specimen from the Transition Coal Measures of Waldershare. I now assign, but also with some doubt, the pinnæ figured in Pl. XI, figs. 2 & 7, to this same species. Three examples in all occur, but in none of them is the nervation quite clearly marked, although there are indications that the lateral veins were probably simple. The form of the pinna, as a whole, as well as the size and shape of the pinnules, their erect and regular nature, and the rounded apices, are features which all resemble those of *P. arborescens* (Schloth.), and I am not aware of any other species with which they may be more closely compared. Yet at Goodnestone these fronds are associated with a Middle Coal-Measure flora.

2. Pecopteris crenulata Brongniart. (Pl. XI, fig. 3.)

1832–34. *Pecopteris crenulata* Brongniart, 'Histoire des Végétaux Fossiles' vol. i, p. 300 & pl. lxxxvii, fig. 1.
1886–88. *Pecopteris crenulata* Zeiller, 'Flore Fossile du Bassin Houiller de Valenciennes' p. 192 & pl. xxv, figs. 1–4.

This species is rare in Britain, and has previously been recorded only from the Upper Coal Measures of the Radstock–Bristol Coalfield. At Barfreston it occurs in the Transition Coal Measures. Prof. Zeiller (see above) has also figured it from the same horizon in the Pas-de-Calais Coalfield, where it is a characteristic plant. In Kent it also occurs in the Middle Coal Measures. The outstanding features of this species are the comparatively long and decurrent pinnules and the crenulate margin.

[1] Arber (1909) p. 28.

Semina incertæ sedis.

SAMAROSPERMUM Arber, 1914.

'Annals of Botany' vol. xxviii, p. 99.

SAMAROSPERMUM MORAVICUM (Helmh.). (Pl. XI, fig. 5.)

1871. *Jordania moravica* Helmhacker, Sitzungsber. K. Böhm. Gesellsch. Wissensch. Prag, p. 81.
1875. *Jordania moravica* E. Geinitz, N. Jahrb. p. 11 & pl. i, figs. 10–11.
1892. *Samaropsis moravica* Zeiller, 'Flore Fossile du Bassin Houiller & Permien de Brive' p. 95 & pl. xv, figs. 9–10.
1914. *Samarospermum moravicum* Arber, 'Annals of Botany' vol. xxviii, p. 99 & pl. vi, figs. 19–20.

This is the first British record of a very rare type of seed, which, for reasons that I have expressed in my recent revision of the British seed-impressions,[1] I have transferred to a new genus, *Samarospermum*. The Kentish specimen appears to be identical with the species first described by Helmhacker (see above), and figured by Geinitz and Zeiller from the Continent, of which only a few examples are known. The generic characters are as follows: Winged, platyspermic seeds, very elongate and narrow, usually broadly rounded at both ends and narrowly elliptical in form. Nucule small, elliptical, situated midway between the apex and the base. Sarcotesta with numerous, fine, parallel, longitudinal striæ.

SAMAROPSIS Gœppert, 1864.

'Fossile Flora der Permischen Formation' Palæontographica, vol. xii, p. 177.

SAMAROPSIS MEACHEMI (Kidst.). (Pl. XIII, fig. 3.)

1889. *Cardiocarpus meachemii* Kidston, Trans. Roy. Soc. Edin. vol. xxxv, pt. 1, p. 330 & pl. —, figs. 5–7.
1914. *Samaropsis meachemi* Arber, 'Annals of Botany' vol. xxviii, p. 98 & pl. vi, figs. 16–17.

This is a rare seed, so far confined to the Middle Coal Measures of Britain, and only recorded from two other localities. It was originally referred to the genus *Cardiocarpus* by Dr. Kidston; but I have recently removed it to *Samaropsis*, on the grounds that the former generic term is best confined to certain platyspermic seeds, which are not winged. The present species has obviously affinity with those seeds that have for many years been referred to *Samaropsis*, of which *S. fluitans* (Dawson) may be regarded as the type.

PLATYSPERMUM Arber, 1914.

'Annals of Botany' vol. xxviii, p. 95.

PLATYSPERMUM RUGOSUM Arber. (Pl. XII, fig. 2.)

1914. *Platyspermum rugosum* Arber, 'Annals of Botany' vol. xxviii p. 96 & pl. vi, fig. 13.

The Mattice Hill seed, shown in Pl. XII, fig. 2, which I have

[1] Arber (1914) p. 90.

recently figured as the type of a new species of a new genus *Platyspermum*, has the following characters:—Seed elongately elliptical, bluntly pointed at both ends, measuring up to 4 cm. or more in length, and about 2 cm. across at its widest part. Ribs broad, prominent, separated by wide shallow grooves, three to five on each side, ribs approximated at the base and at the apex. Testa smooth or very finely striated.

The same seed also occurs in the Upper Coal Measures of Gloucestershire.

CARDIOCARPUS Brongniart, 1828.

'Prodrome d'une Histoire des Végétaux Fossiles' p. 87.

CARDIOCARPUS GUTBIERI Geinitz. (Pl. XII, fig. 3.)

1855. *Cardiocarpon gutbieri* Geinitz, 'Versteinerungen der Steinkohlenformation in Sachsen' p. 39 & pl. xxi, figs. 23–25.
1888. *Cardiocarpus gutbieri* Kidston, Trans. Roy. Soc. Edin. vol. xxxiii, p. 403 & pl. xxiii, fig. 5.
1914. *Cardiocarpus gutbieri* Arber, 'Annals of Botany' vol. xxviii, p. 97 & pl. vi, fig. 15.

This seed is uncommon in Britain, but occurs in both the Upper and the Middle Coal Measures.

DORYCORDAITES Grand'Eury, 1877.

'Flore Carbonifère du Département de la Loire' p. 214.

DORYCORDAITES PALMÆFORMIS (Gœpp.). (Pl. XIII, fig. 6.)

1852. *Nœggerathia palmæformis* Gœppert, 'Fossile Flora des Uebergangsgebirges' Nova Acta Acad. Cæsar. Leop.-Carolin. vol. xxii, Suppl. p. 216 & pl. xv; also pl. xvi, figs. 1–3.
1877. *Cordaites (Dorycordaites) palmæformis* Grand'Eury, 'Flore Carbonifère du Département de la Loire' p. 214 & pl. xviii, figs. 4–5.
1886–88. *Dorycordaites palmæformis* Zeiller, 'Flore Fossile du Bassin Houiller de Valenciennes' p. 632 & pl. xciii, figs. 1–2.

This plant has only once been previously recorded from Britain, from the Middle Coal Measures of Yorkshire. The leaf is rather small and narrow in this species, the nerves being fine, equal in strength, and close. The specimen figured in Pl. XIII, fig. 6 is probably the basal portion of a leaf of this species.

CORDAICLADUS Grand'Eury, 1877.

'Flore Carbonifère du Département de la Loire' p. 241.

CORDAICLADUS APPROXIMATUS Ren. (Pl. XIII, fig. 2.)

1893–96. *Cordaicladus approximatus* Renault, 'Flore Fossile du Bassin Houiller & Permien d'Autun & d'Épinac' fasc. iv, pt. 2, p. 342 & pl. lxxxi, fig. 2.
1914. *Cordaicladus approximatus* Arber, Phil. Trans. Roy. Soc. ser. B. vol. cciv, p. 419 & pl. xxviii, fig. 21.

Cordaicladus is an excessively rare genus in Britain, and this is only the second record of the species from British rocks. The leaf-scars in this species are mounted on cushions, which are closely approximated.

2. Cordaicladus sp. (Pl. XIII, fig. 1.)

A large specimen, showing a somewhat obscure impression of what I take to be the bark of a Cordaitean tree, occurs in the Mattice Hill cores, part of which is figured in Pl. XIII, fig. 1. It is quite unlike any British example of *Cordaicladus* known to me. The leaf-scars (or, rather, the prints which I interpret as being probably leaf-scars) are either horizontal or somewhat oblique, but not curved, grooves, which are fairly distant one from the other. They are certainly different in form from the ordinary Cordaitean leaf-scar, and there is no cushion. The exact nature of this fossil remains, however, doubtful for the present.

XIV. Conclusions as to the Palæobotanical Horizons represented in the Kent Coalfield.

The number of species known from the Kent coalfield has risen from ten in 1892 to twenty-six in 1909, and is now ninety-six, excluding varieties and incomplete determinations. Sixty-eight new records are included in the present paper. Thus, including all determinations, nearly a hundred plants are now known from Kent, either generically or specifically. Of these, twenty-nine species occur in both the Transition and the Middle Coal Measures, and twelve only in the higher, with fifty-five in the lower horizon alone. The occurrence of species, confined to a single horizon, is, however, a matter of secondary importance, as compared with the relative abundance of certain common types, as an indication of the zone. The frequency of occurrence of all the plants recorded in the present paper has been indicated in the lists of records from each boring given in the preceding pages. I now give a complete list of all the fossil plants at present known from the coalfield, including those recorded in previous papers by Prof. Zeiller and by myself, and an indication of their distribution in the two horizons present in Kent.

A Complete List of the Known Fossil Floras of the Coal Measures of Kent.

Species.	Transition Coal Measures.	Middle Coal Measures.
Equisetales.		
Calamites cisti Brongn.	×	×
C. ramosus Art.	×	×
C. suckowi Brongn.	×	×
C. varians Sternb.	—	×
C. undulatus Sternb.	—	×
C. gœpperti Ett.	×	×
Dictyocalamites burri Arber	×	—

Species.	Transition Coal Measures.	Middle Coal Measures.
EQUISETALES (*cont.*).		
Annularia sphenophylloides (Zenker)	×	×
A. stellata (Schl.)	×	—
A. radiata (Brongn.)	×	×
A. galioides (L. & H.)	—	×
Calamocladus equisetiformis (Schloth.)	—	×
C. grandis (Sternb.)	—	×
C. longifolius (Sternb.)	—	×
C. charæformis (Sternb.)	—	×
Calamostachys tuberculata (Sternb.)	×	—
C. longifolia Weiss	—	×
C. germanica Weiss	—	×
SPHENOPHYLLALES.		
Sphenophyllum cuneifolium (Sternb.)	×	×
S. cuneifolium var. *saxifragæfolium* Sternb.	—	×
S. myriophyllum Crép.	—	×
PTERIDOSPERMEÆ and FILICALES.		
Sphenopteris obtusiloba Brongn.	×	×
S. neuropteroides (Boul.)	×	—
S. schillingsi Andrä	×	×
S. cf. *S. laurenti* Andrä	—	×
S. cf. *S. coralloides* Gutb.	—	×
S. cf. *S. (Renaultia) chærophylloides* (Brongn.)	—	×
S. (Renaultia) schatzlarensis (Stur)	—	×
S. (Oligocarpia) brongniarti? (Stur)	—	×
Mariopteris muricata (Schloth.)	×	×
M. latifolia (Brongn.)	×	—
M. cf. *M. sphenopteroides* (Lesq.)	×	—
Neuropteris scheuchzeri Hoffm.	×	×
N. obliqua (Brongn.)	×	×
N. tenuifolia (Schloth.)	×	×
N. ovata Hoffm.	—	×
N. rarinervis Bunb.	×	—
N. acuminata (Schl.)	—	?
N. flexuosa Sternb.	×	—
N. heterophylla Brongn.	—	×
N. gigantea (Sternb.)	—	×
N. schlehani Stur	—	×
N. cf. *N. fimbriata* Lesq.	×	—
Dictyopteris münsteri (Eichw.)	—	×
Odontopteris lindleyana Sternb.	×	—
O. britannica Gutb.	—	×
Alethopteris lonchitica (Schl.)	×	×
A. serli (Brongn.)	×	×
A. decurrens (Art.)	—	×
A. valida Boul.	—	×
A. davreuxi? (Brongn.)	—	×
Lonchopteris rugosa Brongn.	—	×
L. eschweileriana Andrä	—	×
Pecopteris miltoni (Art.)	×	×

Species.	Transition Coal Measures.	Middle Coal Measures.
PTERIDOSPERMEÆ and FILICALES (*cont.*).		
Pecopteris arborescens (Schloth.)	?	?
P. crenulata Brongn.	×	×
P. (Dactylotheca) plumosa (Art.)	×	×
Eremopteris artemisiæfolia (Sternb.)	×	×
Cornucarpus acutus (L. & H.) [1]	×	×
SEMINA INCERTÆ SEDIS.		
Radiospermum perpusillum (Lesq.)[1]	—	×
Samaropsis fluitans (Dawson)	—	×
S. meachemi (Kidst.) [1]	—	×
Cardiocarpus gutbieri Gein.	—	×
Samarospermum moravicum (Helmh.) [1]	—	×
Platyspermum rugosum Arber [1]	—	×
P. elongatum (Kidst.) [1]	—	×
LYCOPODIALES.		
Lepidodendron aculeatum Sternb.	×	—
L. lycopodioides Sternb.	×	×
L. dichotomum Sternb.	×	×
L. ophiurus Brongn.	—	×
L. obovatum Sternb.	—	—
Lepidophloios laricinus Sternb.	—	×
L. acerosus (L. & H.)	—	×
Bothrodendron punctatum (L. & H.)	—	×
Sigillaria tessellata (Steinh.)	—	×
S. ovata Sauv.	—	×
S. elongata Brongn.	—	×
S. rugosa Brongn.	—	?
S. lævigata Brongn.	—	×
S. scutellata Brongn.	—	×
S. principis Weiss	—	×
Asolanus camptotænia Wood	—	×
Stigmaria ficoides (Sternb.)	×	×
Lepidophyllum lanceolatum L. & H.	×	×
L. minus Goode	×	×
L. intermedium L. & H.	—	×
Lepidostrobus variabilis L. & H.	×	×
CORDAITALES.		
Cordaites principalis (Germ.)	×	×
C. borassifolius (Sternb.)	×	×
Dorycordaites palmæformis (Gœpp.)	—	×
Cordaicladus approximatus Ren.	—	×
Cordaicladus sp.	—	×
Cordaianthus pitcairniæ (L. & H.)	—	×
C. volkmanni (Ett.)	—	×
Cordaicarpus cordai Gein.	—	×
C. cf. *C. corculum* (Sternb.)	×	—
C. areolatus (Boul.)	—	?
CYCADOPHYTA.		
Pterophyllum sp.	×	—

[1] See Arber (1914).

With regard to the palæobotanical horizons represented in Kent, there is no indication at present of the presence of Upper Coal Measures. It is true that there is still some doubt as to the location of the highest measures in the field. But if Upper Coal Measures occur at all, which, in my opinion, is more than unlikely, they must lie out to sea in the unexplored ground beneath the English Channel. So far as that portion of the coalfield which underlies land is concerned, one can say without hesitation that the highest beds represented belong to the Transition Coal Measures, and in none of these has a typical Upper Coal Measure flora been found to occur.

The presence of Transition Coal Measures in Kent was first made known by Prof. Zeiller[1] in 1892. In 1909[2] I showed that these beds are well developed in the central region of the coalfield, and in the present paper their distribution has been further traced.

The present communication contains the first proof of the occurrence of Middle Coal Measures in this coalfield, and it has been shown that these beds are there widely developed.

This horizon, the Middle Coal Measures, is the lowest present in the coalfield, so far as it is proved. I can find no evidence of Lower Coal Measures, much less of Millstone Grits (which palæobotanically are simply the lowest beds of the Lower Coal Measures), and I very much doubt whether this horizon is represented in any of the Armorican coalfields of England or Wales. A careful examination of the floras of the borings, recorded in the preceding pages, which have passed through the lowest beds of the measures into the Carboniferous Limestone Series, has not resulted in the recognition of a typically Lower Coal Measure assemblage of plants at this level. There is no change in the flora of these beds as compared with that of the higher beds in the same boring: that is, the plants indicate a Middle Coal Measure flora throughout.

I conclude, therefore, that only two horizons are represented in the Kent coalfield—the Transition and the Middle Coal Measures—, at least so far as the area yet proved is concerned.

The examination of the floras of these new borings has resulted in the most detailed study of the vegetation of the higher part of the Middle and the lower part of the Transition Coal Measures that has as yet been made in any British coalfield. It has confirmed the conclusion, arrived at from a knowledge of the fossil floras of other coalfields, that there is no 'break' between these floras, but rather a perfectly gradual transition from the Middle to the Transition type. For this reason, when near the borderland of these two horizons, it is not possible sometimes to fix, by means of the plants alone, the exact boundary between them within several hundred feet. But, by correlating the lithological records of two or more borings in connexion with their floras, it is usually possible to arrive at an approximate, if somewhat arbitrary, line of demarcation,

[1] Zeiller (1892) & (1894). [2] Arber (1909).

and thus to determine, if only roughly, the number of feet of measures belonging to each horizon, as proved in these borings.

The present study of the Kent coalfield has extended the known vertical distribution of certain species, but not to any marked degree. There is, first of all, the possible, but somewhat doubtful, occurrence of *Pecopteris arborescens?* (Schloth.) in both the Transition and the Middle Coal Measures. *Sphenopteris schillingsi* Andrä and *Pecopteris crenulata* Brongn. are recorded for the first time from the British Transition Measures, and the latter also from the Middle Coal Measures. *Mariopteris latifolia* (Brongn.), *Neuropteris fimbriata?* Lesq., and *Lepidophyllum minus* Goode are also shown to occur on the former horizon. From the Middle Coal Measures we have the first records of *Neuropteris ovata* Hoffm. and *Lepidophyllum intermedium* L. & H. All these species have, however, been previously found on other horizons in Britain. Otherwise the vertical distribution, assigned here to the plants occurring in Kent, agrees with that already published from other coalfields.

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EXPLANATION OF PLATES XI–XIII.

All the specimens are in the Carboniferous Plant Collection, Sedgwick Museum, Cambridge, to which they have been kindly presented by Mr. Arthur Burr. The registered numbers quoted refer to this collection. [The photographs should in several instances be examined with the aid of a hand-lens. They are by Mr. W. Tams, Cambridge.]

Plate XI.

Fig. 1. *Lonchopteris eschweileriana* Andrä, from the Middle Coal Measures of the Stodmarsh Boring, at 1865 feet. No. 2276. $\times \frac{3}{2}$. (See p. 72.)

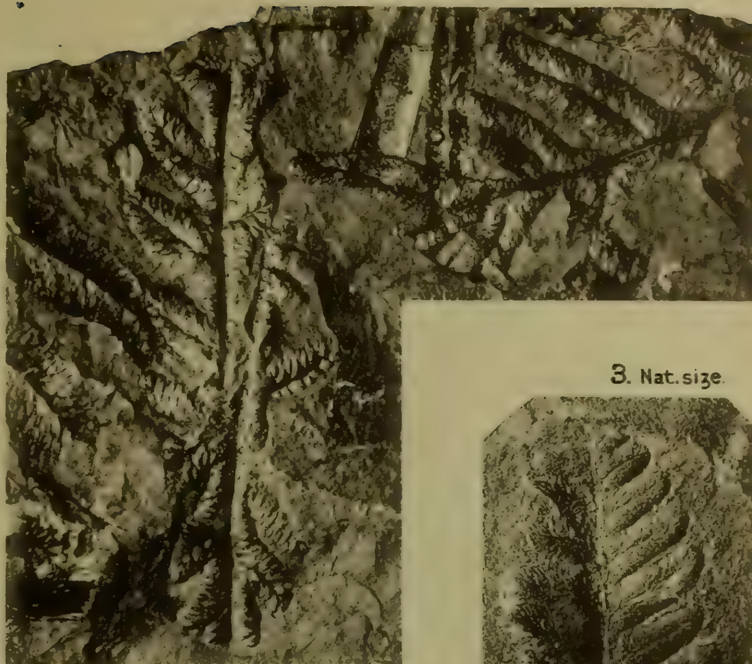
2. *Pecopteris arborescens?* (Schloth.), from the Middle Coal Measures of the Goodnestone Boring, at 2000 feet. No. 2234. Natural size. (See p. 73.)

3. *Pecopteris crenulata* Brongn., from the Transition Coal Measures of the Barfreston Boring, at 2009 feet. No. 2502. Natural size. (See p. 73.)

4. *Dictyopteris münsteri* (Eichw.), from the Middle Coal Measures of the Woodnesborough Boring, at 1618 feet. No. 2434. Natural size. (See p. 72.)

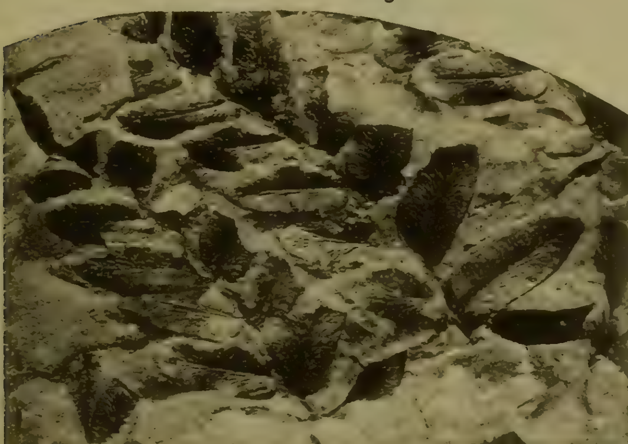
2. Nat. size.

1. × 3/2



3. Nat. size.

4. Nat. size.



7. Nat. size.

6. × 2

5. Nat. size.

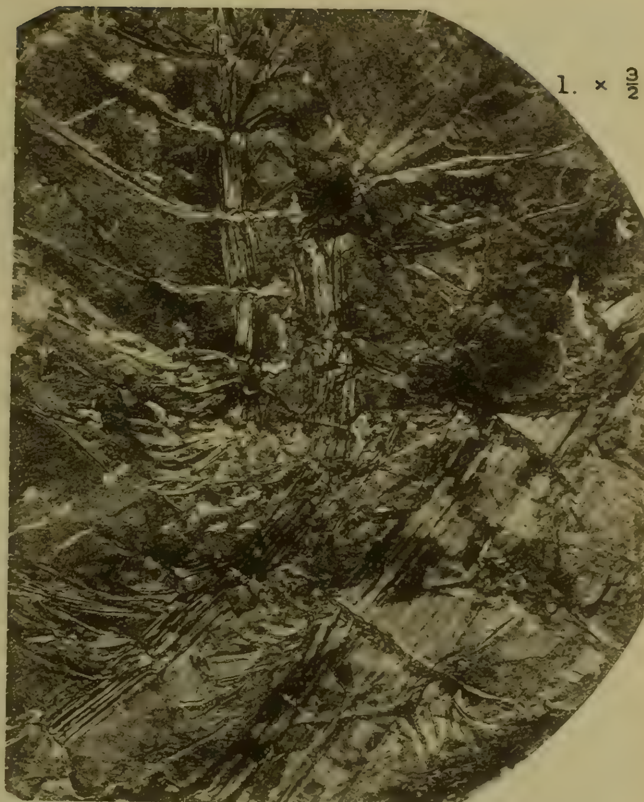
W. Tams, Photo.

Bemrose, Collo, Derby

FOSSIL PLANTS FROM THE KENT COALFIELD.

2. Nat. size.

1. × $\frac{3}{2}$



3. Nat. size.

5. × 2

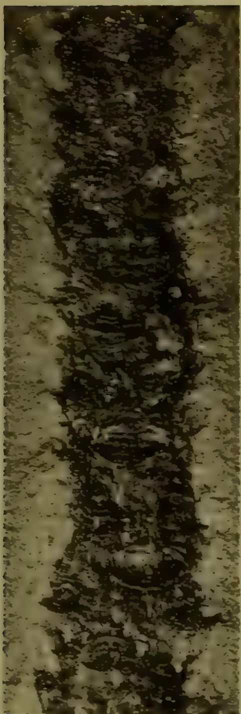
4. × 2

W. Tams, Photo.

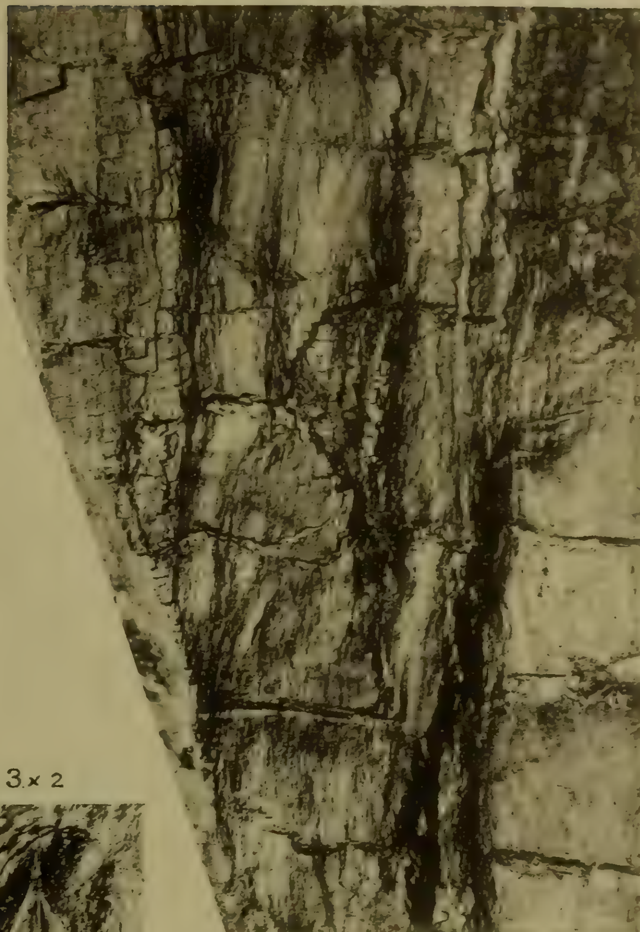
Bemrose, Collo., Derby

FOSSIL PLANTS FROM THE KENT COALFIELD.

2. Nat. size



1. Nat. size.

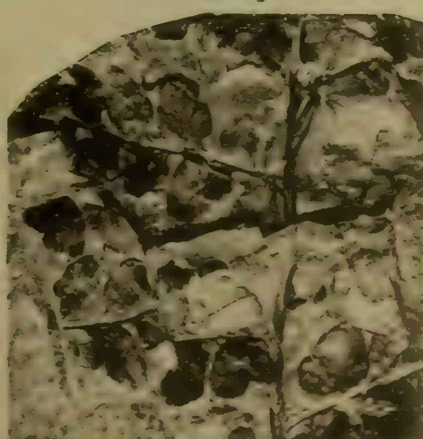


6. Nat. size.

3. × 2

5. × 2

4. Nat. size.



W. Tams, Photo.

Bemrose, Collo, Derby

FOSSIL PLANTS FROM THE KENT COALFIELD.

Fig. 5. *Samarospermum moravicum* (Helmh.), from the Middle Coal Measures of the Oxney Boring, at 2439 feet. No. 2992. Natural size. (See p. 74.)

6. *Neuropteris ovata* Hoffm., from the Middle Coal Measures cf the Woodnesborough Boring, at 1153 feet. No. 2442. × 2. (See p. 71.)

7. *Pecopteris arborescens?* (Schloth.), from the Middle Coal Measures of the Goodnestone Boring, at 2000 feet. No. 2234. Natural size. (See p. 73.)

PLATE XII.

Fig. 1. *Sphenophyllum myriophyllum* Crép., from the Middle Coal Measures of the Oxney Boring, at 3168 feet. No. 3001. × $\frac{3}{2}$. (See p. 70.)

2. *Platyspermum rugosum* Arber, from the Middle Coal Measures of the Mattice Hill Boring, at 1484 feet. No. 2337. Natural size. (See p. 74.)

3. *Cardiocarpus gutbieri* Gein., from the Middle Coal Measures of the Mattice Hill Boring, at 1111 feet. No. 2375. Natural size. (See p. 75.)

4. *Mariopteris latifolia* (Brongn.), from the Transition Coal Measures of the Barfreston Boring, at 1626 feet. No. 2492. × 2. (See p. 71.)

5. *Sphenopteris (Renaultia) schatzlarensis* (Stur), from the Middle Coal Measures of the Walmestone Boring, at 1290 feet. No. 3002. × 2. (See p. 71.)

PLATE XIII.

Fig. 1. *Cordaicladus* sp., from the Middle Coal Measures of the Mattice Hill Boring, at 1463 feet. No. 2334. Natural size. (See p. 76.)

2. *Cordaicladus approximatus* Ren., from the Middle Coal Measures of the Mattice Hill Boring, at 1168 feet. No. 2405. Natural size. (See p. 75.)

3. *Samaropsis meachemi* (Kidst.), from the Middle Coal Measures of the Woodnesborough Boring, at 1176 feet. No. 2465. × 2. (See p. 74.)

4. *Sphenopteris schillingsi* Andrä, from the Middle Coal Measures of the Goodnestone Boring, at 2005 feet. No. 2236. Natural size. (See p. 71.)

5. *Odontopteris britannica* Gutb., from the Middle Coal Measures of the Oxney Boring, at 3341 feet. No. 3003. × 2. (See p. 72.)

6. *Dorycordaites palmæformis* (Gœpp.), from the Middle Coal Measures of the Trapham Boring, at 2610 feet. No. 2250. Natural size (See p. 75.)

3. Supplementary Note *on the* Discovery *of a* Palæolithic Human Skull *and* Mandible *at* Piltdown (Sussex). By Charles Dawson, F.S.A., F.G.S., and Arthur Smith Woodward, LL.D., F.R.S., Pres.G.S. With an Appendix by Prof. Grafton Elliot Smith, M.A., M.D., V.P.R.S. (Read December 17th, 1913.)

[Plates XIV & XV.]

Contents.

I. Geology and Flint-Implements. [C. D.]

Since reading our paper on December 18th, 1912,[1] we have continued our researches in the Piltdown gravel.

The whole bed is divided into four well-defined strata. The topmost consists of surface-soil, containing pieces of iron-stained subangular flint derived from some ancient gravel, similar to those beneath. This surface-soil also contains a mixture of pottery and implements of various ages.

Beneath is the second bed of undisturbed gravel, varying from a few inches to 3 feet in thickness. It is from the centre of this bed that the triangular Palæolithic implement mentioned and figured in our former paper[2] was obtained. It contains rolled and subangular flints similar to those found in the strata above and below, and is mostly pale yellow in colour with occasional darker patches.

The third bed, though not always present, is well marked, where it does occur, by reason of its dark ferruginous appearance, and chiefly consists of pieces of ironstone and rolled and subangular flints deeply patinated and iron-stained. As in most other beds of this description, the ferruginous colour of the gravel and of the fossils within it often varies in intensity, from a dull pale-brown to a lustrous blue-black, within the space of a few inches, the latter colour being due to the presence of ferrous sulphide of iron.

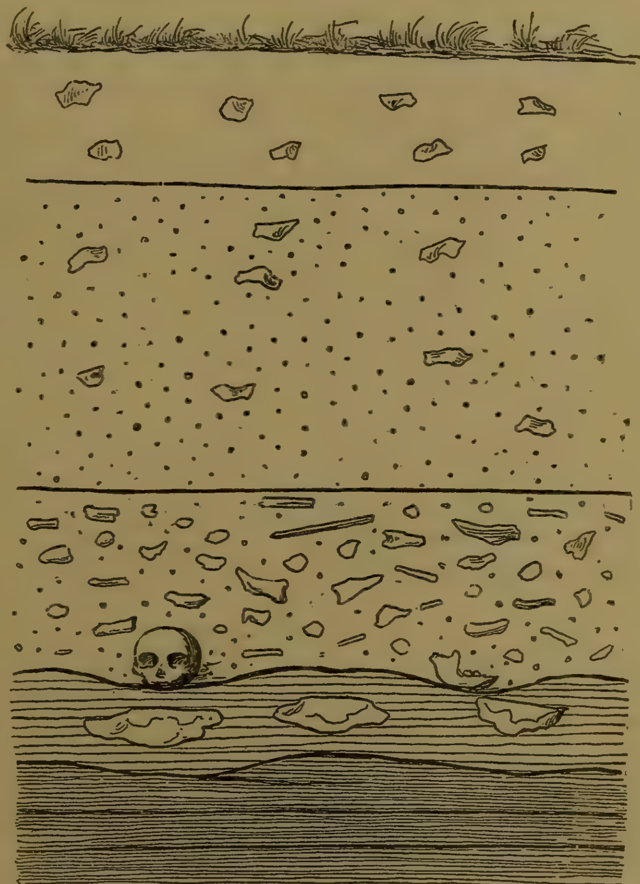
[1] Q. J. G. S. vol. lxix (1913) pp. 117–44.

[2] *Ibid.* p. 122, footnote 1 & pl. xvi, fig. 2. I find that my former description of these worked flints has been repeatedly misquoted. I took care not to describe these artefacts as of Chellean a g e; but, for purposes of comparison, I mentioned the work u p o n o n e f a c e of the implements as being s i m i l a r to those of the Chellean s t a g e, that is, one of culture. How far culture can be 'zoned' with age remains to be proved, but there must always exist obvious limitations to such a system.—*C. D.*

All fossils found by us (with the exception of the remains of deer) were discovered or have been traced to this third dark bed.

The dark bed rests unevenly upon a fourth, which we identified this year. It consists of very pale-yellow, finely-divided sand and clay, and appears to be a sort of solidified mud reconstructed from the Wealden strata beneath it (Tunbridge Wells Sand, Hastings Beds). This fourth stratum, less than a foot thick, has so far proved unfossiliferous, but contains flints of a much larger size

Fig. 1.—*Section of gravel-bed at Piltdown (Sussex). Approximate scale = 1/24 of the natural size.*



than any of those in the overlying strata. These big buff-coloured flints vary from 6 to 15 inches in length by 3 to 6 inches in width. They are usually flat on one side and uneven and hummocky on the other, which gives them a very characteristic appearance. As they lie in the bed their flat sides are uppermost, and where they impinge upon the bed above they are deeply stained with iron. They are thickly patinated, and saturated to the core with iron.

The character of these flints is often so changed as to resemble ironstone, and some can be scratched and disintegrated with a penknife. This feature may well account for the apparent absence of flints overlying the still higher and older strata in the Weald. They have a roughly-smoothed surface, but bear no striations or 'frost-fractures.' The presence of flints of so large a size, and comparatively little worn and rolled, in the middle of the Wealden area, is a point of great interest. No implements or 'Eoliths' have occurred in this bed, although the latter are fairly common in all the overlying strata.

A few derived Chalk fossils have been found by us in the flints from the gravels, and include (according to Mr. C. D. Sherborn and Mr. T. H. Withers) :—

Echinocorys vulgaris (= *E. scutatus* Leske), of the shape characteristic of the zone of *Micraster cor-testudinarium.*

Inoceramus inconstans (Woods), also a form typical of the same horizon.

The tabular flints so common in the Piltdown gravel are doubtless derived from the regular layers which occur at the base of the zone of *Micraster cor-anguinum*, and in the upper part of the zone of *M. cor-testudinarium.* In age, therefore, the derived Chalk fossils and the flints are very similar, belonging to an horizon well exposed at present in the southern Chalk escarpment (as, for example, at Offham) near Lewes.[1]

Our first work this year was to clear away completely all débris overlying the floor of the dark gravel-bed from the vicinity of the spot where the mandible and piece of occipital bone were found last year, so that the irregularities of its level might be fully exposed. We found that the floor was full of depressions, often measuring 2 to 7 feet across and 1 to 2 feet in depth. Into these depressions had been drifted the dark ferruginous gravel, and in places there yet remained small undisturbed patches. The area so exposed by us measured about 20 feet square.

Following a small rift or channel in the floor which was yet filled with undisturbed gravel, we discovered another fragment of a tooth of *Stegodon* bearing three cusps. This specimen was worked out very carefully, and preserved in the gravel matrix. It seems probable, from its general appearance and condition, that this fragment is a portion of the same molar as that to which the two fragments found last year belonged: like them, it is shattered, and shows little sign of rolling. If so, it must have been broken before its original deposition, and not by the workmen. The other portions were found about 10 yards away, in débris composed of the dark gravel.

In a depression adjoining that in which a portion of the human mandible occurred, was found what appears to be a flint-flake roughly worked on one face and stained dark brown (Pl. XIV,

[1] 'Cretaceous Rocks of Britain: the Upper Chalk' Mem. Geol. Surv. vol. iii (1904) pp. 46–47.

figs. 1 *a*–1 *c*); also a triangular flint of Palæolithic outline (Pl. XIV, figs. 2 *a*–2 *c*), but having 'Eolithic' 'edge-chipping' about the apex, the colour and patination resembling those of the 'Eolithic' forms found in the pit generally. Among some of the disturbed gravel in the pit Dr. Smith Woodward found a flint worked on one face and simply flaked on the other face, and similar to the Palæolithic flints described in our last paper.

An incisor of a Beaver (*Castor fiber*) and portion of a mandible occurred in the dark gravel: the former close to the spot where the molars were found last year, and the latter some 12 yards away to the south. One of the molars agrees in size with a socket of the alveolar border.

The whole of the work was perforce carried on very slowly, and we found it impossible to employ more than one labourer, for the actual excavation had to be closely watched, and each spadeful carefully examined. The gravel was then either washed with a sieve, or strewn on specially-prepared ground for the rain to wash it; after which the layer thus spread was mapped out in squares, and minutely examined section by section.

While our labourer was digging the disturbed gravel within 2 or 3 feet from the spot where the mandible was found, I saw two human nasal bones lying together with the remains of a turbinated bone beneath them *in situ*. The turbinal, however, was in such bad condition that it fell apart on being touched, and had to be recovered in fragments by the sieve; but it has been pieced together satisfactorily by Mrs. Smith Woodward.

All the gravel *in situ* excavated within a radius of 5 yards of the spot where the mandible was found, was set apart and searched with especial care, and was finally washed and strewn as before mentioned. It was in this spread that Father Teilhard de Chardin, who worked with us three days last summer, on August 30th, 1913, discovered the canine tooth of *Eoanthropus*, hereafter described. In this way also Dr. Smith Woodward recovered a small fragment of a tooth of *Rhinoceros*, in the same state of mineralization as the fragments of teeth of *Stegodon* and *Mastodon*.

There now remains little excavation to be done in the immediate vicinity of the site of these remains. Other excavations which we have made in the pit have so far proved unproductive of fossils; but we have opened up some trial-holes which give evidence of a continuation of the bedded gravel to the west, under the plough-land there, and across the small valley on the east near Moon's Farm House.

Conclusions.

We cannot resist the conclusion that the third or 'dark bed' is, in the main, composed of Pliocene drift, probably reconstructed in the Pleistocene Epoch. The evidence seems to point towards a marking-off of the third or 'dark bed' from the second or lighter bed, that contained a triangular Palæolithic implement,

one face only of which was worked and was struck in a manner somewhat similar to those of the Chellean stage.

As regards the human remains discovered, including the canine tooth, there is nothing in their mode of occurrence to favour the idea that they may have belonged to different individuals. Putting aside the human remains and those of the beaver, the remains of the fauna all point to a characteristic land fauna of Pliocene age; and, though all are portions of hard teeth, they are rolled and broken.[1] The human remains, on the other hand, although of much softer material, are not rolled, and the remains of beaver are in a similar condition. It would, therefore, seem that the occurrence of these two individuals belongs to one of the periods of reconstruction of this gravel, though for other reasons before stated by us, this is not perfectly certain.[2]

II. Description of the Nasal Bones and Lower Canine Tooth of *Eoanthropus dawsoni*, and some Associated Mammalian Remains. [A. S. W.]

Eoanthropus dawsoni.

A further study of the cranium of *Eoanthropus* shows that the slight longitudinal ridge along the outer face at the hinder end of the parietal region is not median, but one of a pair such as frequently occurs in the lower types of human crania. The occipital and right parietal bones thus need slight re-adjustment in the published reconstruction (as described by Prof. G. Elliot Smith in an appendix to this paper, p. 93), but the result does not alter essentially any of the conclusions already reached. The only real addition to our knowledge of the skull is made by the discovery of the nasal bones.

Like the cranial elements, the nasal bones are comparatively stout; and they are thickened at the upper border, suggesting a massive and somewhat overhanging brow-ridge. They are so well preserved that they fit perfectly at the median suture, and show that they form a gently-rounded arch, constricted above and widening below, but with scarcely any upturning at the lower border (Pl. XV, figs. 1 *a*–1 *d*). Both are narrower above than below, and the bone of the right side is considerably wider in its upper part than that of the left side. Below the irregular roughening at the upper thickened end, the outer face of the bone is nearly smooth; while the inner face of each is marked, as usual, with the longitudinal groove for the nasal nerve (Pl. XV, figs. 1 *c* & 1 *d*, *n.*). The left nasal (figs. 1 *b* & 1 *c*) is complete, and shows well the extension of the infero-external angle, by which the slightly-concave, free lower border of the bone is lengthened. The right nasal (Pl. XV, fig. 1 *d*)

[1] That of *Stegodon* probably presented a more rolled appearance before it was shattered.

[2] See Discussion, Q. J. G. S. vol. lxix (1913) p. 151.

is obviously broken at this angle. The following are some measurements (in millimetres):—

Width of naturally apposed nasals at the upper end				13
Width of naturally apposed nasals at the lower end (about)				15
Length of the median suture				14
Maximum length of the nasals				18
Length of the upper border of the left nasal				7
Do.	do.	do.	right nasal	10
Do.	lower	do.	left nasal	10
Do.	do.	do.	right nasal (about)	11

Comparison proves that these nasal bones resemble those of the existing Melanesian and African races, rather than those of the Eurasian type.

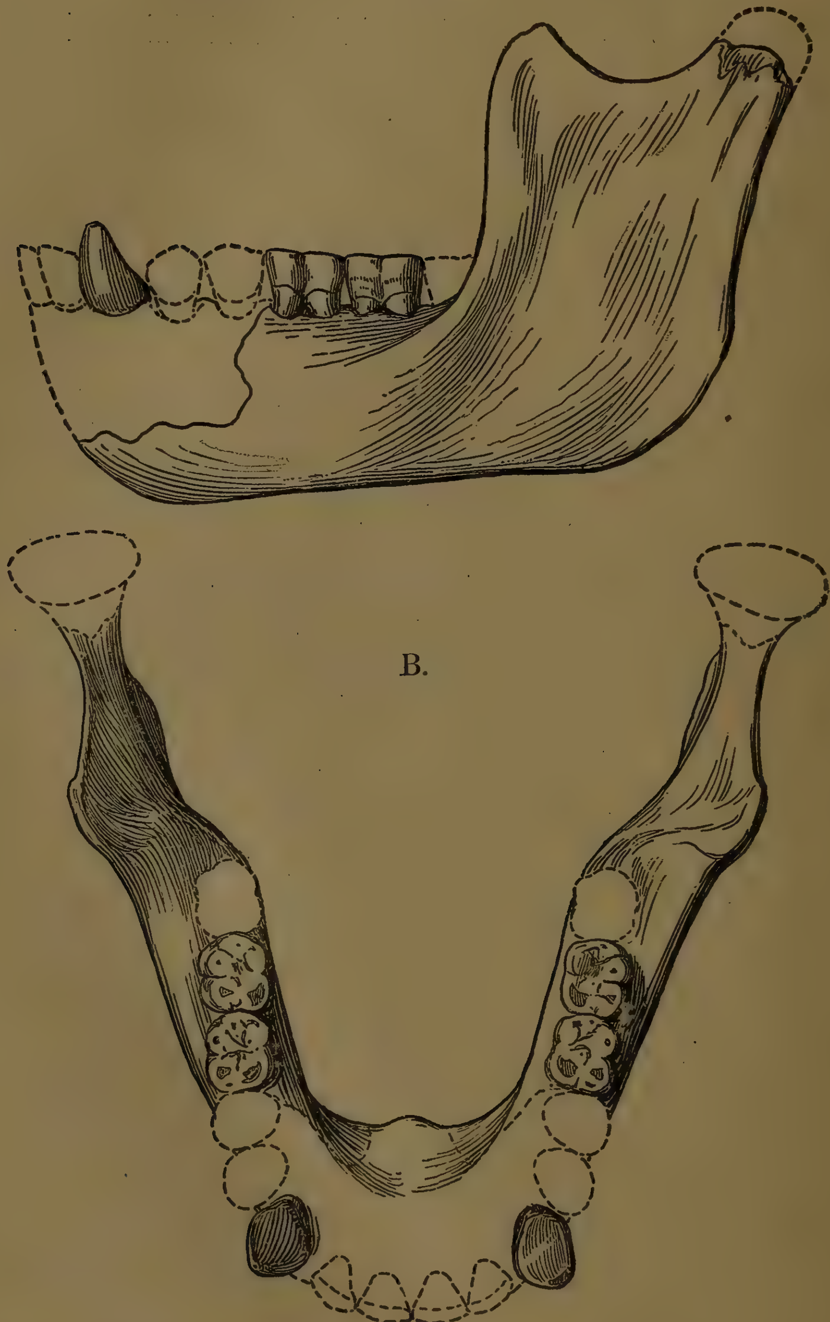
The remains of a turbinal found beneath the nasal bones are too much crushed and too fragmentary for description; but it may be noted that the spongy bone is unusually thick, and has split longitudinally into a series of long and narrow strips.

The remarkable new canine tooth (Pl. XV, figs. 2 *a*–2 *e*) is certainly that of a Primate Mammal, and may therefore be referred without hesitation to *Eoanthropus*. As it belongs to the right side of the mandible, corresponds in size with the jaw already found at the same spot, and agrees with the molar teeth in having been considerably worn by mastication, it may almost certainly be regarded as part of the specimen previously described. No trace of the socket for the tooth is seen in the bone preserved at the symphysial end of the fragmentary mandible, but its position can be determined approximately by reference to the corresponding tooth in the Apes.

The crown of the tooth is conical in shape, but much laterally compressed, so that its inner (lingual) face is concave, while its outer (labial) face is only gently convex. The extreme apex is missing, but whether by wear or by accidental fracture cannot be decided. In the upper half of the outer face (Pl. XV, fig. 2 *a*) the thin layer of enamel is shown, marked by the usual faint transverse striations (or imbrications); but below this the tooth is encrusted with a film of hydrated oxide of iron, which has broken away at the base of the crown, removing the enamel with it. The darkly-stained dentine is thus exposed here, and the only mark of the lower limit of the crown is a faintly-impressed transverse line just above the constricted neck of the tooth. The enamel on the inner face of the crown (Pl. XV, fig. 2 *b*) has been completely removed by mastication, while that of the outer face, showing its prismatic structure, is exposed in worn section along the edges of the apical portion. The surface of wear forms a simple gently-curved concavity, evidently produced by a single opposing tooth; and it extends to the basal edge of the crown, as indicated by the clear ending of the cement along its lower margin. It is probably almost parallel with the original inner face of the crown, and the wear has been sufficient near the apex to expose the secondary dentine at the upper end of the pulp-cavity. The

Fig. 2.—*Restoration of the mandible of* Eoanthropus dawsoni, *in left side side view* (A) *and upper view* (B) *; two-thirds of the natural size.*

A.

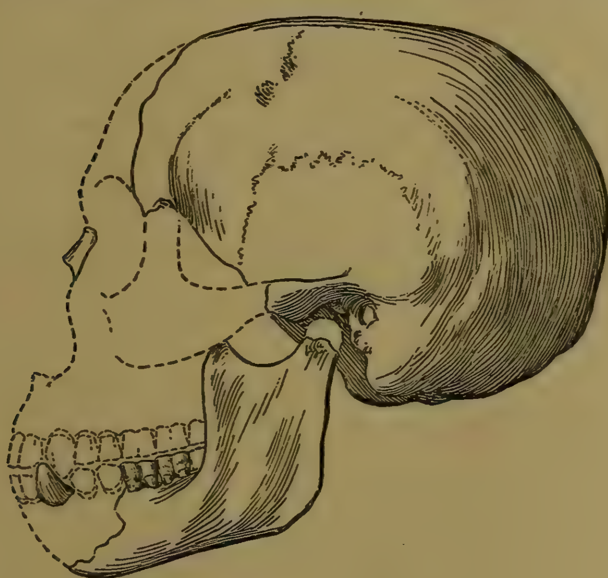


extent of this pulp-cavity, which is widely open at the lower end of the root, is well shown in two radiographs prepared by Mr. Archibald D. Reid (Pl. XV, figs. 3*a* & 3*b*). It is filled with grains of ironstone or sand. The anterior (median-interstitial)

edge of the crown (Pl. XV, fig. 2*c*) widens below to a triangular tumid area, which is sharply bounded by the outer face, the inner worn face, and the constricted neck of the tooth. Whether or not this area was originally covered to any extent by enamel is uncertain: appearances rather suggest that it is invested, instead of enamel, with a direct continuation of the cement-layer of the root. The posterior (lateral interstitial) edge of the crown (Pl. XV, fig. 2*d*) is sharp, and is not produced below into any inner (lingual) protuberance or heel.

The root of the tooth is complete, somewhat deeper than the crown, and tapers only slightly downwards from the constricted neck

Fig. 3.—*Restoration of the skull and mandible of* Eoanthropus dawsoni, *left lateral view; nearly a third of the natural size.*



to the truncated lower end. It is irregularly ovoid in transverse section (Pl. XV, fig. 2*e*), the postero-external (lateral-interstitial + labial) face being gently convex, while the antero-internal (median-interstitial + lingual) face is flattened. It is invested with a distinct layer of cement, which is seen in cross-section both at the lower end and at the base of the crown on the inner (lingual) face. Much of this cement, especially on the flattened face, appears to be deposited in small, ill-defined, and irregularly-arranged globules.

The following measurements (in millimetres) may be cited:—

Depth of crown preserved (measured along the outer face) ...	11·5
Maximum (antero-posterior) width of crown	10·0
Do. (interno-external) breadth of crown	10·5
Do. width of the worn inner face	9·0
Depth of root	18·0
Width of flattened face of root at the upper end..................	9·5
Do. do. do. do. at the lower end	7·0
Smaller diameter of root at the upper end	7·0
Do. do. do. at the lower end	5·0

The canine tooth thus described is distinctly larger than any hitherto found in the genus *Homo*, and differs fundamentally in having completely interlocked with its opposing tooth, which worked downwards on its inner face as far as the edge of the gum. Its exact position in the jaw remains uncertain, but its crown must have risen well above the level of the other teeth, and its state of wear implies its separation from the anterior premolar by a slight diastema, as in the Apes. If the root was originally inclined in a plane almost parallel with that of the anterior end of the jaw, as in the Apes, the crown must have been more nearly upright than that shown in the hypothetical restoration which I made a year ago.[1] If, also as in the Apes, the flattened face of the root was almost parallel with the plane of the mandibular symphysis, the concave worn face of the crown would be turned completely backwards and inwards (that is, towards the tongue). In this case (Pl. XV, fig. 4, and figs. 2–3, pp. 88 & 89) the opposing upper canine tooth must have been shorter and wider than the permanent upper canine in the Recent Apes, for in them the worn surface of the lower canine is continued at least slightly over the outer (labial) side of the crown behind, so that it is visible in lateral-external view. There is no evidence of wear by the outer upper incisor, such as sometimes occurs in the Apes; for this wear leaves a small facette in a plane distinct from that made by the canine, and never extends more than about half-way down the crown.

The degree of wear of this newly-discovered canine tooth is of especial interest, when considered in connexion with the worn condition of the first and second molars in the mandible to which it apparently belongs. As already described, both these molars are flattened by mastication down to the level of the middle area of their crown, while the third molar (known only by its socket) must have been fully in place (see Pl. XV, figs. 5 *a* & 5 *b*). The permanent canine should therefore be completely extruded and in use, whether the order of appearance of the teeth corresponded with that in Man or with that in the Apes. As, however, the enamel of its inner face is not merely worn, but entirely removed by mastication, the tooth must have been well used for a considerable period. It probably, therefore, came into place before the second and third molars, as in Man—not after one or both of these teeth, as in the Apes.

This appearance of a human order of tooth-succession in the mandible of *Eoanthropus* suggests the desirability of making a very careful comparison between the shape of the tooth now described, and that of the lower canine in Man as well as in the Apes. As is already known, the permanent canine in some of the Australian and Tasmanian aborigines is comparatively large, with its blunt apex slightly projecting above the level of the dental series; but in this tooth, as in the more normal human

[1] Q. J. G. S. vol. lxix (1913) p. 133, fig. 4 *b*.

permanent canine, the outer (labial) face of the crown is comparatively narrow and deep, and is not continued in a gradual curve round the posterior (lateral interstitial) face to the same extent as in the fossil tooth. The milk-canine of Man, however, may be much more satisfactorily compared. In this tooth the gently-convex outer (labial) face of the acuminate crown (Pl. XV, fig. 6 *a*) is relatively wider than in the permanent canine, and gradually curves round to the posterior (lateral-interstitial) face, exactly as in the fossil (Pl. XV, figs. 2 *d* & 6 *d*); while the inner (lingual) face (fig. 6 *b*) is distinctly concave, and, if its enamel were removed, would correspond very closely with the worn face of the latter specimen (fig. 2 *b*). Seen from the flattened anterior (median interstitial) face (Pl. XV, figs. 2 *c* & 6 *c*), these two canines appear to be remarkably similar in shape, although, as might be expected, the root is somewhat the shorter in the milk-tooth. In all the existing Apes, and in the extinct *Dryopithecus*, the permanent lower canine is more conical than that of *Eoanthropus*, with a more extensive production inwards of the base of the crown on the lingual side. It also appears to be usually larger and stouter in proportion to the size of the jaw. The crown of the milk-canine in the Apes, however, like that in Man, is much more compressed, with a concave inner (lingual) face and a gently-convex outer (labial) face, so that it closely approaches the fossil in shape (Pl. XV, figs. 8 *a*–8 *d*): the only noteworthy difference being that, in the Apes, there is already the characteristic small produced heel or ledge at the base of the crown, at the hinder (median-interstitial) end of the inner (lingual) face.

It results, therefore, from these comparisons that, among known Upper Tertiary and Recent Anthropoids, the permanent lower canine of *Eoanthropus* agrees more closely in shape with the milk-canine both of Man and of the Apes than with the corresponding permanent tooth in either of these groups. It is also obvious that the resemblance is greater between *Eoanthropus* and *Homo* than between the former and any known genus of Apes. In other words, the permanent tooth of the extinct *Eoanthropus* is almost identical in shape with the temporary milk-tooth of the existing *Homo*. Hence it forms another illustration of the well-known law in mammalian palæontology, that the permanent teeth of an ancestral race agree more closely in pattern with the milk-teeth than with the permanent teeth of its modified descendants.

In this connexion, it is interesting to add that even in *Homo sapiens*, if the base of the crown of the canine were raised in the gum to the same level as that of the adjacent teeth, its apex would frequently project well above the rest of the dental series. The relatively large size and depth in the milk-dentition is especially well seen in a preparation in the Central Hall of the British Museum (Natural History); see Pl. XV, fig. 7.

For valuable help in making these studies, I have again to thank Mr. W. P. Pycraft and Prof. Arthur S. Underwood.

The Associated Mammalia.

STEGODON.

The new fragment of a molar of *Stegodon* is part of an unworn plate showing three cusps in line, the outermost being smaller and much less elevated than the two others. It evidently belongs to the hinder end of a molar, and it may perhaps be part of the same specimen as the fragments already described.

RHINOCEROS. (Pl. XIV, figs. 3 *a* & 3 *b*.)

Rhinoceros is represented only by the anterior crest of an upper cheek-tooth, which has been broken and rolled before burial, and is as highly mineralized as the pieces of molars of *Stegodon* and *Mastodon*. This specimen has, therefore, the appearance of a derived fossil. As shown in anterior view (fig. 3 *a*) the crown is rather low, and as seen from above (fig. 3 *b*) the inner expansion of the crest is very wide at the base. The basal cingulum is preserved only on the anterior face, and does not appear to have extended round the inner end of the crest. The enamel of the inner expansion is almost smooth, but that on the sides of the thin part of the crest is marked by a coarse rugosity and a few vertical corrugations. The specimen cannot be specifically determined with certainty; but, on direct comparison, it is found to agree best with the anterior crest of upper premolar 3 of *Rhinoceros mercki* (= *Rh. leptorhinus* Owen) and *Rh. etruscus*. So far as general shape is concerned, it might belong to either of these species; but, as pointed out to me by Prof. Boyd Dawkins, the peculiar coarse rugosity of the enamel is most closely similar to that of *Rhinoceros etruscus*.

CASTOR.

A fragment of the alveolar portion of the inner face of the right mandibular ramus of *Castor* corresponds in size with the true molar described last year.[1] This tooth, in fact, fits well the socket for m. 2. The newly discovered lower incisor may also, perhaps, belong to the same mandible.

EXPLANATION OF PLATES XIV AND XV.

PLATE XIV.

Fig. 1. Flaked flint, showing few flakings on one face (1 *a*), a simple flake on the other face (1 *b*), and its tabular shape in edge-view (1 *c*). Natural size. (See p. 84.)

2. 'Eolith,' showing flaked edge (2 *a*), simply-flaked face (2 *b*), and edge-view (2 *c*). Two-thirds of the natural size. (See p. 85.)

3. *Rhinoceros* cf. *etruscus* Falconer: imperfect anterior crest of right upper premolar 3, front view (3 *a*) and inner view (3 *b*). Natural size. (See p. 92.)

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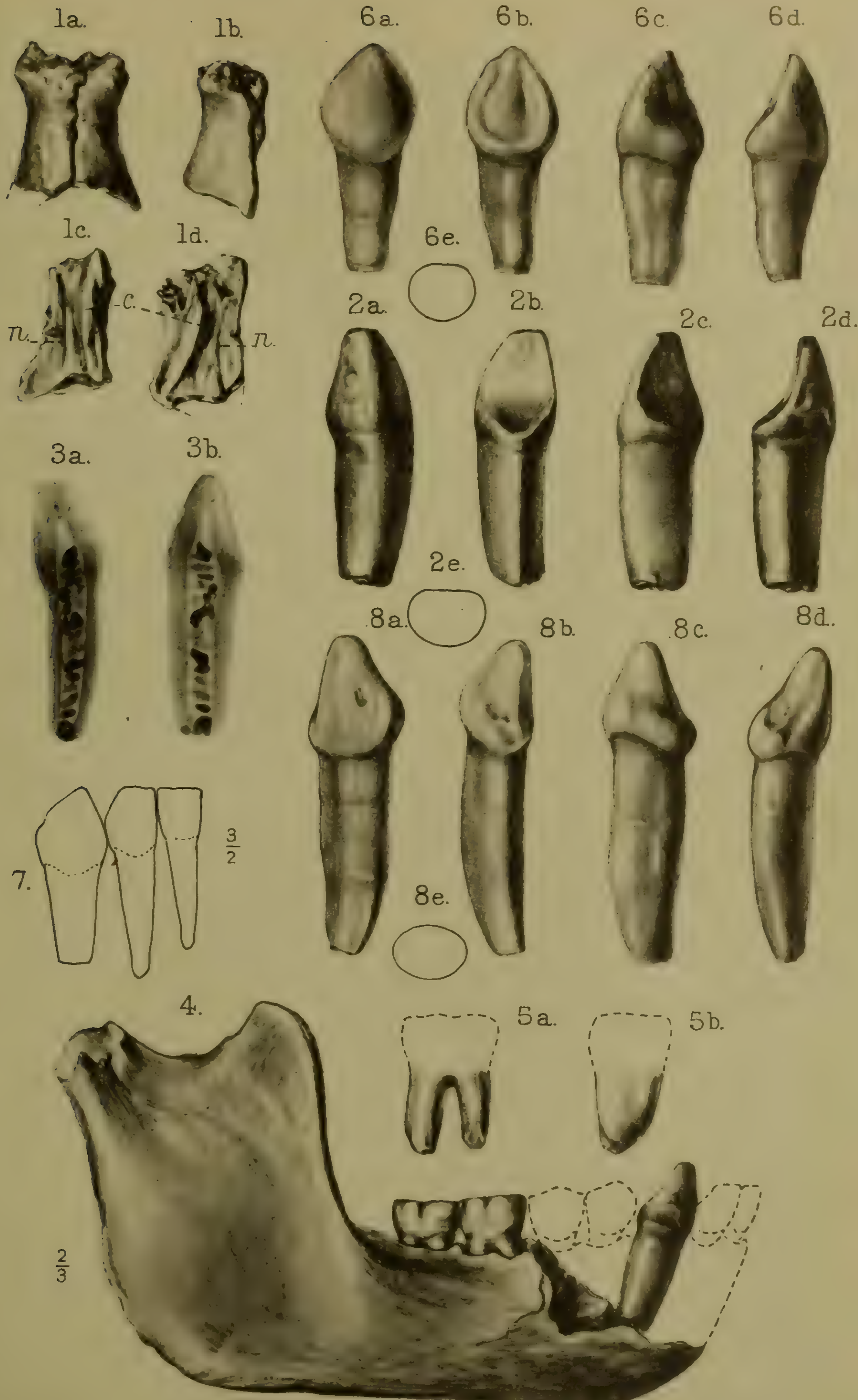
[2] Q.J.G.S. vol. lxix (1913) p. 143 & pl. xxi, fig. 7.

G. M. Woodward, del.

Bemrose, Collo., Derby.

FLINTS AND RHINOCEROS FROM PILTDOWN (SUSSEX).



G. M. Woodward, del.

Bemrose, Collo., Derby

EOANTHROPUS, HOMO, SIMIA.

PLATE XV.

Fig. 1. *Eoanthropus dawsoni* A. S. Woodward: nasal bones in front view (1 *a*), left side view (1 *b*), with left nasal from within (1 *c*) and right nasal from within (1 *d*). Natural size. *c.*=inner crest; *n.*=groove for nasal nerve. (See p. 86.)

2. Do.: right lower canine tooth in outer or labial view (2 *a*), inner or lingual view (2 *b*), anterior or median-interstitial view (2 *c*), posterior or lateral-interstitial view (2 *d*), and outline transverse section of neck (2 *e*). Natural size. (See pp. 87–89.)

3. Do.: radiograph of the right lower canine tooth from without (3 *a*) and in side view (3 *b*). Natural size. (See p. 88.)

4. Do.: right mandibular ramus with canine tooth, outer view. Two-thirds of the natural size.

5. Do.: impression of cavity for roots of lower molar 3; outer (5 *a*) and anterior (5 *b*) views, with crown in restored outline. Natural size.

6. *Homo sapiens* Linn.: right lower milk-canine in outer or labial view (6 *a*), inner or lingual view (6 *b*), anterior or median-interstitial view (6 *c*), posterior or lateral-interstitial view (6 *d*), and outline transverse section of neck (6 *e*). Twice the natural size. (See p. 91.)

7. Do.: right lower milk-canine and milk-incisors, outer antero-lateral view. Three-halves of the natural size. (See p. 91.)

8. *Simia satyrus* Linn.: right lower milk-canine in outer or labial view (8 *a*), inner or lingual view (8 *b*), anterior or median-interstitial view (8 *c*), posterior or lateral-interstitial view (8 *d*), and outline transverse section of neck (8 *e*). Four-thirds of the natural size. (See p. 91.)

APPENDIX.—*On the* EXACT DETERMINATION *of the* MEDIAN PLANE *of the* PILTDOWN SKULL. By Prof. G. ELLIOT SMITH, M.A., M.D., V.P.R.S.

At the meeting of the Geological Society which was held on December 18th, 1912, I gave my first impressions of the cranial cast which Dr. Smith Woodward had sent me three days before the meeting.

On the present occasion it is not my intention to say anything further in reference to the brain of *Eoanthropus* (because I am preparing a full report upon it for presentation to the Royal Society[1]); but, as there has been considerable criticism of the restoration of the brain-case, I should like to take this opportunity of expressing my opinion that none of the criticism has affected the accuracy of the preliminary note upon the cranial cast which I communicated to this Society in December 1912.[2]

As the correct restoration of the cranium was the necessary preliminary to any detailed study of the form of the brain, Dr. Smith Woodward kindly permitted me to examine the fragments of the skull, and make an independent investigation with the view of determining what positions they originally occupied in the skull. This examination revealed a multitude of structural features which indicate precisely the true position and orientation of each of the fragments; and there is now no doubt that the

[1] [Communicated to the Royal Society at the meeting on February 19th, 1914.]

[2] Q. J. G. S. vol. lxix (1913) pp. 145–47.

reconstruction of the skull which Dr. Smith Woodward exhibited to the Geological Society in December 1912 was a much closer approximation to the truth than any of the various models so far exhibited in public by his critics.

In the course of my examination of the fragments last November, I found that the anterior end of the sagittal suture was present on the largest fragment (fig. 4, *S*, below). The recognition of this suture directed my attention to other features of the

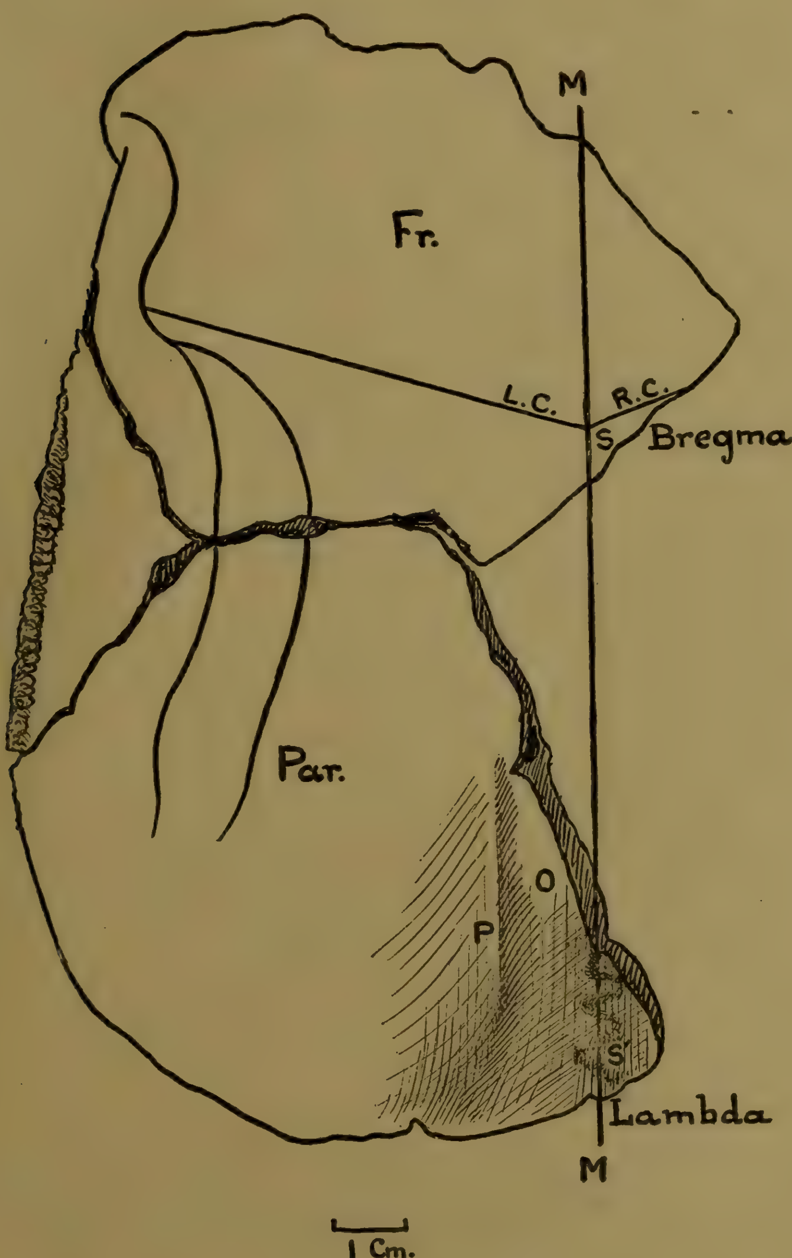
Fig. 4.—*Drawing representing the sutures in the bregmatic region, traced from a photograph; three-halves of the natural size.*

frontal and parietal bones, which enabled me to determine the precise location (*M*) of the median line of the skull.

In fig. 5 (p. 95) I have represented diagrammatically the information to be gained from the study of the large fragment, when viewed in *norma verticalis*. The left half of the coronal suture is an obtrusive feature of this fragment. It pursues a very irregular course, but the general direction of the suture is indicated in the diagram by the line *L.C.* (fig. 5). The exact pattern formed by its medial extremity is shown in fig. 4 (*L.C.*), which is a tracing from an excellent photograph taken by my assistant, Mr. Henry Gooding.

Careful examination of the fragment also revealed a small part of the right half of the coronal suture (fig. 4, *R.C.*), the presence of which had already been detected by Dr. Smith Woodward.

Fig. 5.—*Diagram of the upper aspect of the largest of the Piltdown fragments.*

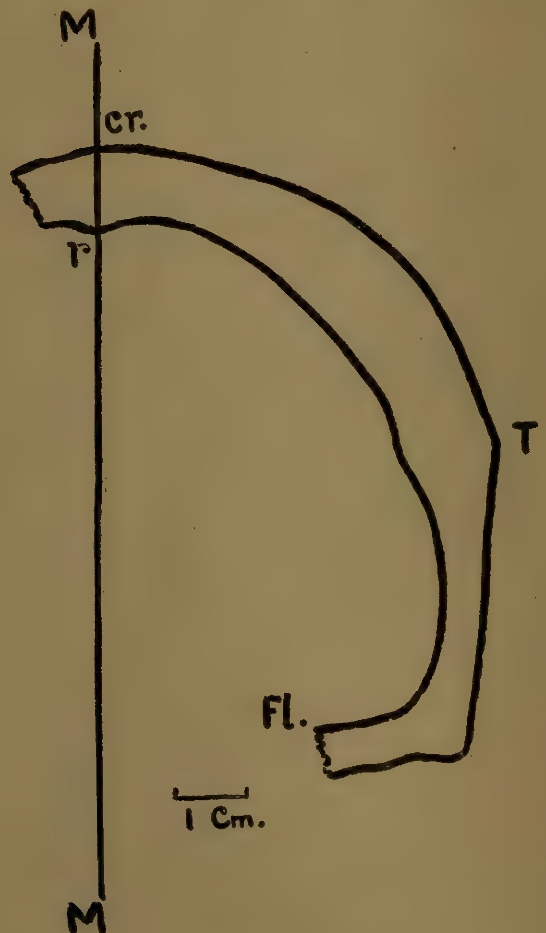


At the place of meeting of the two halves of the coronal suture, which is slightly to the right of the median plane (fig. 4), there is a diminutive bregmatic bone (*b*). At its posterior border the

sagittal suture (S) begins, and pursues a tortuous course towards the broken edge of the bone.

The presence of this part of the sagittal suture affords positive evidence of close proximity to the true median line. The anterior extremity of the sagittal suture often becomes deflected a few millimetres to one side or the other of the median line; but, except in those rare cases where a large bregmatic bone is present, the deviation is never considerable. In the course of an examination

Fig. 6.—*Transverse section through the frontal bone, a short distance in front of the bregma.*



of the collection of crania now in the Anatomical Department of the University of Manchester, I found several examples in which the anterior end of the sagittal suture closely resembled that of the Piltdown skull (fig. 4, p. 94).

Along the line corresponding to that labelled M in the diagrams, a well-defined longitudinal ridge (fig. 6, r, above) was found upon the endocranial aspect of the frontal bone. Careful examination

of the fossil shows that this ridge corresponds to the place where the two halves of the frontal bone originally came together at the metopic suture. Although it is not uncommon to find in the crania of primitive man a metopic crest upon the outside of the frontal bone (that is, at the spot marked *cr.* in fig. 6, p. 96), an endocranial metopic crest is of much rarer occurrence. It is found, however, in the neighbourhood of the bregma in the Neanderthal skull; and there is no doubt of its identity in the specimen now under consideration.

Mr. Frank Barlow called my attention to the fact that, if this fragment be looked at from in front (or a transverse section of a cast of it, fig. 6, be studied), the curve of the frontal bone describes a gentle sweep above the temporal ridge (*T*), which reaches its summit (*cr.*) directly above the endocranial ridge (*r*), beyond which it begins its descent, showing that it has crossed the middle line to the right side. This affords independent corroborative evidence of the correctness of the determination of the median plane (*M*).

My friend Prof. J. T. Wilson, F.R.S., has pointed out that the inclination of the floor of the anterior cranial fossa (fig. 6, *Fl.*) provides further evidence in support of my contention. For, if the bone be tilted laterally to even a small extent, the floor would become inclined at an angle such as is unknown in any skull, whether human or simian.

If the median line thus determined in the region of the bregma (fig. 5, p. 95) is prolonged backwards, it cuts the posterior corner of the parietal in the neighbourhood of the lambda (fig. 5). Independent evidence, derived from (*a*) the study of the manner of articulation of the left parietal and temporal bones, and their relationship to the occipital; (*b*) the texture of the endocranial surface of the bone along the line *M*; (*c*) the fact that the transverse section of the supralambdoid flattening (*O*) is horizontal only when the bone is placed as it is represented in the diagram; and (*d*) the situation and relations of the parasagittal crest (*P*),—all confirms the accuracy of the identification of the median plane as it is represented in fig. 5.

If the fossil be held in a certain light, a series of depressions (*S′*) can be detected, which closely resemble those found in the supralambdoid region of skulls (such as the Neanderthal calvaria) where the sagittal suture has recently become closed. The suggestion is that the posterior end of the sagittal suture conformed to the pattern represented at *S′* in fig. 5, and had recently closed when the Piltdown man met his death. This may occur in modern man at any age between 30 and 40 years—although, in rare instances, it may happen before 30, or (more often) be delayed beyond 40. There are reasons for believing that this individual was a young adult, and possibly a female: for the features that present secondary sexual characters in modern skulls are quite indefinite in these fragments.

DISCUSSION.

Prof. A. KEITH congratulated the Authors on the progress made during the last twelve months. He was glad to note that the particular stratum in which the remains of *Eoanthropus* had been found was being distinguished from the more superficial stratum in which flints of the Chellean type had been found. He ventured to say that, if no human remains had been discovered in the deeper or Eoanthropic stratum, no one would have hesitated in regarding it as of Pliocene age. He was glad to note that the hinder end of the skull of *Eoanthropus* had been opened out to a considerable degree; but, in his opinion, the occipital and temporal bones were still placed wrongly. When these defects were removed, and the two sides of the skull made approximately symmetrical, it would be found that the brain-capacity was about 1500 c.c. The brain-cast of the skull, as originally reconstructed, was just under 1200 c.c.; it was difficult to see how widening out of the skull would reduce the capacity to 1100 c.c. Two other difficulties that he had encountered were (1) the presence of a pointed projecting canine in the jaw, and an articular eminence at the glenoid fossa of the skull; and (2) a much-worn canine tooth in a jaw in which the third molar tooth—according to the published X-ray photograph of the Piltdown mandible—was not completely erupted. He agreed that all three parts—skull, jaw, and canine tooth—must be assigned to *Eoanthropus*, but he was not convinced that they could all belong to the same individual.

Prof. W. J. SOLLAS thought that the Authors were to be congratulated on the complete nature of the proof which they had reached by a study of minute anatomical characters. A system of reconstruction which afforded different results from those obtained in this direct and positive manner seemed to require some amendment. The presence of derived fossils in a gravel was one of the commonest facts, not encountered here for the first time, and geologists had followed their usual method in dating the Piltdown gravel by the most recent fossils contained in it: these showed it to be Pleistocene. The topographical relations of a gravel are of some value as evidence, and confirm this conclusion. The precise horizon in the Pleistocene was less definitely known; unfortunately, the flints which had been found in association with the skull were not sufficiently characteristic to determine this point.

Prof. W. BOYD DAWKINS said that he would only take up, at that late hour, one of the many points raised by Prof. Keith—the age of the Piltdown deposit. It was clearly proved to be later than the Pliocene by the presence of an antler of red deer (*Cervus elaphus*), a species unknown in the Pliocene of Europe, and abundant in the Pleistocene and later strata. He agreed with the Authors of the paper in their conclusion that the deposit belongs to an early stage of the Pleistocene Epoch.

Prof. A. S. Underwood said that he would confine his remarks to the two molars and the socket of the third molar in the Piltdown mandible. He had been prepared to show the radiograph at the Royal College of Surgeons in the summer, but Prof. Keith had been unable to place a lantern at his disposal. The two molars were worn down by use, to such an extent that it was impossible that the individual could have been less than 30 years of age, probably a good deal more. The sockets of the third molar were not those of an erupting tooth, the roots had been quite completed, and the tooth was in its final position at death. This was very plainly shown in the radiograph. Had the third molar been erupting or about to erupt, the roots could not have been on a plane with those of the other molars.

Mr. C. Dawson thanked the Fellows for their kind reception of the paper. He specially wished to record the thanks of the Authors to Mr. George M. Maryon-Wilson (the Lord of the Manor) and his tenant, Mr. Robert Kenward, for their kind permission to make excavations in the gravel-bed at Piltdown.

Dr. A. Smith Woodward and Prof. G. Elliot Smith also briefly replied.

4. *On an* APPARENTLY PALÆOLITHIC ENGRAVING *on a* BONE *from* SHERBORNE (DORSET). By ARTHUR SMITH WOODWARD, LL.D., F.R.S., Pres. G.S. (Read March 11th, 1914.)

THIRTY-SEVEN years ago Prof. Boyd Dawkins[1] described to the Society the incised figure of a horse on a piece of bone found with Palæolithic implements and remains of Pleistocene mammals in the Robin Hood Cave, Creswell Crags. Until the present time, this has remained the sole example of the pictorial art of Palæolithic Man met with in Britain. It is, therefore, of interest to record the discovery of a second specimen, which appears to date back to the same period, and is especially remarkable as being almost identical with the first, both in subject and in style.

The new specimen was found by two boys of Sherborne School, A. S. Cortesi and P. C. Grove, and was submitted to me by Mr. R. Elliot Steel, to whom I am indebted for the opportunity of

Incised drawing of the head and forequarters of a horse on a fragment of rib, natural size; from a dry valley north of Sherborne (Dorset). In the Museum of Sherborne School.

making this communication. It was picked up, with fragments of calcspar and miscellaneous Inferior Oolite fossils, in an old heap of quarry-débris near the Bristol road, on the outskirts of Sherborne (Dorset); and there can be no doubt that it was originally obtained from one of the small dry valleys with steep sides which furrow the dip-slope of the Inferior Oolite north of the town. A careful consideration of all the circumstances suggests that it may have occurred in a rock-shelter, which was destroyed by quarrying: for the heap of débris which yielded the specimen was most probably derived from a sheltered spot with a south-western aspect, which would serve admirably for human habitation. Unfortunately, the only noteworthy associated specimens are a few flints, which are not clearly chipped by man, although they must have been brought from a distance of several miles. It may, however, be added that at a spot a quarter of a mile farther down the dry valley, where it joins the next valley, Mr. Steel has recognized a Pleistocene

[1] Q. J. G. S. vol. xxxiii (1877) p. 592, fig. 1.

deposit, from which he has collected teeth of the mammoth and the woolly rhinoceros.

The bone is a piece of rib, 8·5 cms. in length, from which the greater part of the flat inner face and the thin anterior border have been flaked away. A remnant of the flat inner face is pierced by a small vascular foramen near the posterior border. The specimen cannot be identified with certainty, but it agrees well in shape with part of an anterior rib of the existing Mongolian wild horse (*Equus przewalskii*). It terminates at one end in a sharp oblique cut, while the other end is irregularly broken. The engraving represents only the head and forequarters of a horse in side view, but it covers the greater part of the outer convex face of the bone, which has not been artificially smoothed. The head points towards the cut end, while the mane fringes the broken thin anterior border. The outline is bold, and executed in short strokes, mostly about 5 or 6 mm. in length, by an instrument which has left a groove with a V-shaped cross-section. The head is well-shaped, with an indication of the mouth in one stroke, but no clear mark of the nostrils. The eye is represented by two nearly parallel strokes, of which the upper is stronger than the lower; and its anterior border is completed by two slight indentations. Two thick strokes in front of the mane are evidently intended for the ears. The mane is indicated by a close series of finer vertical lines: these are nearly parallel; but sometimes they cut each other, and sometimes merge together by the accidental flaking of the intervening surface of the bone. The longest of these fine lines are on the top of the head, where they extend farthest downwards. A coarse groove marking the line of the back begins just below the hinder part of the mane, and ends posteriorly in some engraving of an uncertain nature. An equally coarse antero-posteriorly directed groove below this on the flank cannot be interpreted; while another shorter groove on the neck, close to its lower margin immediately behind the head, is also curious.

As already mentioned, this new specimen is remarkably similar in design to that previously discovered in the Creswell Caves; but in the latter the incised lines are much finer and more numerous, and the flat surface on which they are engraved has been first carefully rubbed smooth. Both agree with the majority of the engravings on bone from the French caves, in representing a hog-maned horse with a relatively large head.

Discussion.

The Chairman (Dr. H. H. Bemrose) said that the communication was of great interest to all. He was familiar with all the Derbyshire caves, including the celebrated Creswell Cave, in which the original engraved bone had been discovered by Prof. W. Boyd Dawkins.

Sir Henry Howorth believed that the engraved bone was of Palæolithic age. The artistic faculty was characteristic only of

Palæolithic Man, and appeared to be greatly debased in the later or Neolithic type. Certainly the workmanship did not resemble that of the still later Bronze Age. The hog-maned horse again, of which he believed the existing Japanese pony to be a survival, apparently did not exist in Europe in Neolithic times.

Mr. W. DALE said that he was present when the incised bone from Creswell Crags was first shown, and recollected the fine series of mammalian teeth and bones associated with it, which were shown at the same time. The fauna was Pleistocene, and the implements undoubtedly Palæolithic.

Mr. A. S. KENNARD wished to congratulate the Author on the importance of the find. Hitherto the only known relic of Late Palæolithic art from these islands was the well-known example from the Robin Hood Cave, and doubts had been expressed whether it really was *in situ* in that cavern—hence this additional find was of the utmost importance. It was noteworthy that, while such relics were common in France, they were extremely scarce in England.

Mr. C. D. SHERBORN explained that the cuts on the bone were not those of a knife, but rather of a graving-tool like the burin of the line-engraver.

Dr. A. P. YOUNG asked whether the set of lines, prolonged so as to reach below the level of the roots of the hairs of the mane in front, might not have been intended to represent a forelock.

Mr. S. H. WARREN said that the evidence for the dating of the specimen rested largely upon its artistic style. He had given a good deal of attention to the Later Palæolithic art, and especially to the comparison of its style with that of the artistic productions of modern savages, and with the later prehistoric art of Europe. In the case of the Bushmen and some other modern savages, there was a certain general resemblance to Palæolithic art, but in his opinion this had often been exaggerated. In its essential qualities the Later Palæolithic art stood out as something different from the art of any other people.

The Neolithic art bore no comparison with that of the Magdalenian age. The only Neolithic animal engravings known to the speaker that were reminiscent of the earlier style, were some found in the dolmens of Portugal; but even this was exceedingly debased art.

After examining the specimen on the table, one could have no hesitation in stating that its artistic style was characteristically Palæolithic, and there could be no doubt of its Palæolithic age.

During recent years evidence had accumulated upon the Continent, which showed that some kind of halter was placed upon the heads of horses in the Magdalenian age, and there could be little doubt that the wild horse was habitually tamed, although it had probably not been domesticated. It was, therefore, very probable that certain designs seen on the flanks of the animals in the Palæolithic engravings were intended to represent a pack. The speaker wondered whether the more indefinite lines

upon the flank of the engraving exhibited might not also have a similar significance.

The AUTHOR, in reply, expressed his gratification that there appeared to be general agreement as to the Palæolithic age of the engraving. Although the long anterior strokes of the mane might have the intention suggested by Dr. Young, he thought that an artist of such skill would have made a more exact drawing if he had attempted to represent a forelock. He could not recognize any suggestion of harness or trappings in the marks on the flank. The specimen belonged to the Sherborne School Museum, and he thanked Mr. Elliot Steel for the opportunity of exhibiting it to the Society.

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CONTENTS.

PAPERS READ.

[No. 278 of the Quarterly Journal will be published next June.]

[The Editor of the Quarterly Journal is directed to make it known to the Public that the Authors alone are responsible for the facts and opinions contained in their respective Papers.]

*** The Council request that all communications intended for publication by the Society shall be clearly and legibly written on one side of the paper only, with proper references, and in all respects in fit condition for being at once placed in the Printer's hands. Unless this is done, it will be in the discretion of the Officers to return the communication to the Author for revision.

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Vol. LXX. JUNE 30th, 1914. No. 278.
Part 2.

THE

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OF THE

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EDITED BY

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Session 1914–1915.

1914.

Wednesday,	November	4*—18
„	December	2 —16*

1915.

Wednesday,	January	6*—20*
„	February (*Anniversary*, Friday, Feb. 19)	3*—24*
	March	10 —24*
	April	14 —28*
„	May	12*
„	June	9 —23*

[*Business will commence at Eight o' Clock precisely.*]

The asterisks denote the dates on which the Council will meet.

upon the flank of the engraving exhibited might not also have a similar significance.

The AUTHOR, in reply, expressed his gratification that there appeared to be general agreement as to the Palæolithic age of the engraving. Although the long anterior strokes of the mane might have the intention suggested by Dr. Young, he thought that an artist of such skill would have made a more exact drawing if he had attempted to represent a forelock. He could not recognize any suggestion of harness or trappings in the marks on the flank. The specimen belonged to the Sherborne School Museum, and he thanked Mr. Elliot Steel for the opportunity of exhibiting it to the Society.

5. *The* Ordovician *and* Silurian Rocks *of the* Lough Nafooey Area (County Galway). By Charles Irving Gardiner, M.A., F.G.S., and Prof. Sidney Hugh Reynolds, M.A., Sc.D., F.G.S. (Read January 7th, 1914.)

[Plates XVI & XVII.]

Contents.

I. Introduction.

The area with which this paper deals is a direct continuation of the Kilbride area (described by us in 1912), from which it is only separated by the Finny River. It forms a tract measuring about 4 miles in length, and about a mile and a half in width. It is bounded on the north by Lough Nafooey, on the north-east by the Finny River, and on the south-east by the inlet of Lough Mask known as Kilbride Bay. On the south and west the boundaries are not determined by any well-marked features.

Geographically the area forms a ridge, rising to its highest points in the hills known as Curraghrevagh (1615 feet) and Benbeg (1788 feet). There is a steep northward descent from this lofty ridge to Lough Nafooey, while the southern descent is more gradual. A second and lower ridge diverges from the main one to the south of Red Island (see map, Pl. XVII), and extends north-eastwards towards the Finny River. Between these two ridges is a valley occupied by two streams, which join and flow into the Finny River: we propose to call this Two-Stream Valley.

Little has been written about this area, the only detailed account being in the Memoir of the Geological Survey of Ireland to accompany Sheet 94, published in 1878; but references to it are to be found in the Summary of Progress of the Geological Survey for 1896, p. 49.

The published map of the district shows a stretch of tuffs bounding the southern shore of Lough Nafooey, with a thick mass of felsite on the south, which is followed by Salrock Beds (Ludlow), and these by Upper Llandovery deposits. As will be seen later, the beds mapped as tuff are in the main the basement-beds of the immense series of grits and conglomerates known now as the Mweelrea Grits, which compose the Formnamore plateau on the north, and the lower part of which has been shown by Mr. Maufe and Mr. Carruthers to be of Llandeilo age. The felsite of the Survey is a thick series of spilite-flows, while the so-called 'Ludlow Beds' are in reality the lower members of the Llandovery Series.

A list of the other papers bearing upon the geology of the Kilbride district will be found in our paper on that area,[1] and, as the list for the Lough Nafooey district would be identical, it will not be repeated. Brief reports by the Committee of the British Association appointed to investigate the igneous and associated rocks of the Glensaul and Lough Nafooey districts were read at the Dundee meeting in 1912, and at the Birmingham meeting in 1913.

The incompleteness of the 6-inch Ordnance Survey maps forms a serious hindrance to satisfactory mapping in this part of Ireland.

II. The Sedimentary and Volcanic Arenig Rocks.

As in the Kilbride area, the Arenig rocks are principally of igneous origin, consisting of a great thickness of spilite-lava associated with fine tuff and coarse breccia, and with a scanty development of ordinary sediments. They occupy a strip of country from a third to half a mile wide, which extends along the northern part of the area, between the Mweelrea Grits on the north and the Silurian strata on the south.

(*a*) The Spilites (Pillow-Lavas).

The spilite-lavas predominate over the fragmental rocks far more in the Lough Nafooey area than in that of Kilbride. They form the top of the ridge at Bencorragh, and extend for about half a mile to the east and to the west of the summit of the hill; while they are exposed almost continuously in the lower ground on the north from end to end of the area. They are in the main dark-green fine-grained rocks, and are often highly amygdaloidal, the amygdules frequently consisting of epidote. Their most characteristic feature, however, is the pillow-structure, which, while occurring at numerous points, is particularly well-marked at the top of Bencorragh. The arrangement of the vesicles in rows concentric with the margin is not very general. As in the Kilbride area, the spilite is frequently associated with abundant chert, which occupies the interstices between the pillows. This is particularly well seen in

[1] Q. J. G. S. vol. lxviii (1912) p. 76.

the lower part of Two-Stream Valley (see fig. 1, below). Although, as a rule, phenocrysts are seldom observed in a hand-specimen, at the western end of the area, near the Curraghrevagh stream, numerous porphyritic albites occur.

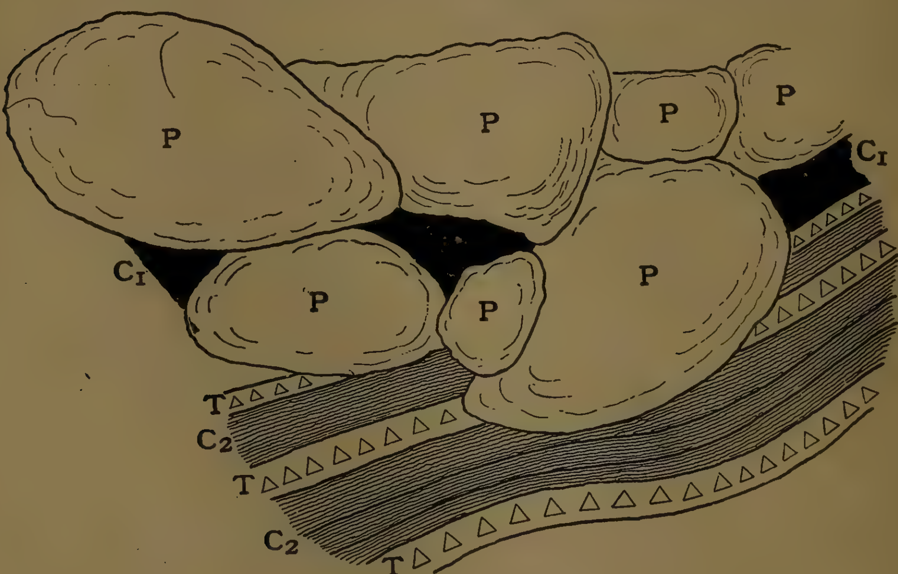
(b) The Sedimentary and Pyroclastic Rocks.

Although the various rock-types are intimately associated, it seems better in describing them to adopt a petrological classification rather than a geographical one.

(1) The Coarse Breccias.

As in the Kilbride area, these rocks consist of spilitic and felsitic breccias, the two kinds of fragments being occasionally intermingled. Breccias do not cover nearly so extensive an area

Fig. 1.—*Diagrammatic sketch showing the relations of the tuffs, cherts, and spilites in Two-Stream Valley, Nafooey.*



[Approximate scale: 1 inch = $1\frac{1}{2}$ feet.]

P=Pillows. T=Tuff. C_1=Chert in irregular patches. C_2=Bedded chert.

relatively to the spilites as they do at Kilbride. The large mass of breccia seen west of Finny, in the Kilbride area, continues across the Finny River into the Lough Nafooey area; but the eastern part of the mass is largely hidden by alluvium, while the western part is much interrupted by intrusions of felsite. A band of coarse breccia, which lies along the southern border of this felsite, is easily traceable, owing to its conspicuous appearance. It consists of angular fragments of a fine-grained felsite weathering white, and of red and green chert, enclosed in a green matrix. It resembles very closely the band of breccia associated with the *Didymograptus-extensus* Shales seen on the southern slopes of

Greenaun in the Glensaul district. The lie of the breccias themselves is not apparent, but the fact that they overlie the spilites on the south is proved by the occurrence along part of their southern border of red sandy shales and cherts dipping northwards at 70°. In Two-Stream Valley these breccias and felsites are cut off on the west by a fault, and for about a mile westwards, that is, as far as the stream which is shown in the 6-inch Ordnance Survey map as entering Lough Nafooey at the promontory half a mile west of Red Island, only small patches of breccia occur associated with the spilites and lying near the boundary of the Mweelrea Grits. To the west of this stream, however, a large patch of felsitic breccia is exposed; and a still larger patch of tuff, mainly of fine grain, is seen round the hamlet of Curraghrevagh.

These rocks are nearly all vertical, and strike more or less east and west; but on the steep north-western slope of Bencorragh a band of breccia, 12 feet wide, associated with a bostonite-dyke, occurs, striking in a north-north-easterly direction. This and another smaller patch, half a mile east of the top of Bencorragh, are the only breccias that we have found in the heart of the spilites.

(2) The Shales, Cherts, and Fine Tuffs.

At several points the breccias and spilites of the north-eastern part of the area here described are associated with fine tuffs and cherts. Thus, at a spot not far from the Finny River, the breccias include a band of fine tuff and red chert dipping northwards at 82°; while the shales and cherts near the line of junction of the felsite-mass, south-west of these breccias, with the spilites, have already been mentioned. On the western side of the fault which brings the breccia against the spilite of Two-Stream Valley, red shales and cherts are seen along two lines. The southern one begins at a waterfall where 12 feet of chert, shale, and grit are associated with a small felsite-dyke, and are traceable westwards in the spilite for a third of a mile: the strata being vertical throughout their whole length of outcrop. The more northerly series of exposures is longer and far less continuous. The strata are first seen in the lower part of Two-Stream Valley, where the united streams, immediately after their junction, pass through a little gorge. Here the rocks are vertical, and the succession from north to south is:—

	Thickness in feet.
Red chert	10
Fine tuff	18
Red chert	2
Spilite.	

The relation of tuffs, cherts, and spilites at one locality on the right bank is shown in the accompanying sketch (fig. 1, p. 106). The cherts contain abundant evidence of the presence of very small radiolaria. Dr. G. J. Hinde, F.R.S., who kindly confirmed our opinion on this point, writes that

'the large majority are simple spheres or ellipses, which would be placed under *Cenosphæra* or *Cenellipsis*; there is an elongated form with rounded

ends, which might come under *Amphibrachium*, and two conical forms which might be *Dictyomitra* or *Stichocapsa*. But in all there are only bare outlines remaining, partitions and meshwork have all disappeared. One object in the slide from the spot marked 103 is a fragment of a fair-sized sponge-spicule.'

It will be convenient here to allude to the fact that similar radiolaria were found in banded chert, at a point marked 62 on our map (Pl. XVII), two-thirds of a mile farther west. Higher up the more northerly of the two streams, other exposures of chert occur, at first vertical, but as one passes farther west dipping southwards—at one point at an angle of 60°.

After one has crossed the col at the head of the valley, further chert-bands, dipping in a general southerly direction, are seen. The fine tuffs associated with the limestone-breccias (see below), a third of a mile west-south-west of Red Island, are vertical or dip southwards at a very high angle.

Thus, while in the eastern part of the Lough Nafooey area the tuffs, cherts, and other sediments dip northwards and overlie the spilites, farther west they dip southwards, that is below the spilites, an intermediate area occurring where these rocks are vertical. These facts seem most readily explicable on the supposition that the western strata with the southerly dip are really inverted. If this be the case, the cherts and limestone-breccias belong to the upper part of the spilitic series, and the Lough Nafooey area is in accord with the Kilbride area, in which the fossiliferous cherts and shales occur high in the spilites—as also with the Glensaul and Tourmakeady areas, in which the limestone-breccias belong to the upper part of the Arenig development.

(3) The Calcareous Rocks.

The districts of Tourmakeady and Glensaul are characterized by a peculiar type of calcareous deposit—limestone-breccia; and Mr. Maufe and Mr. Carruthers have described a similar rock from the Upper Arenig of the Leenane district. No such rock was seen in the Kilbride area, but in the Lough Nafooey area it is again found at two localities, one a third of a mile south-west of Red Island, the other at Curraghrevagh hamlet. The characters of this deposit may best be studied at the former locality. As in the Tourmakeady and Glensaul areas, the matrix consists of coarse quartzose grit or sometimes tuff, enclosing fragments of chert and felsite and pieces of grey, red, and white limestone, generally of a compact horny texture, and of all sizes up to the length of 14 inches. Pieces of crinoid-stem are fairly common in the limestone, and a fragment of an *Illænus* was found; in the matrix only a few unrecognizable fragments of trilobites and brachiopods were met with, together with a Cystidean plate, concerning which Dr. Cowper Reed writes that it suggests *Echinoencrinus senckenbergi* H. von Meyer, a Lower Ordovician form. Near Curraghrevagh, limestone-breccia is seen in and near the stream at the north-eastern end of the hamlet, and it has been worked in one field immediately north, and in another about

200 yards west-south-west of the hamlet. The last two exposures, however, are now overgrown, and the breccia is no longer visible. At all these localities the limestone-breccias appear to be vertical.

III. The Mweelrea Grits and Conglomerates (Llandeilo).

These grits and conglomerates, which bound the Kilbride area on the north-west, were not described in our paper on that area, while in our earlier papers on the Glensaul and Tourmakeady districts they are referred to as of (?) Bala age.

As shown in our map (Pl. XVII), they form a band about 300 yards wide, extending along the southern shore of Lough Nafooey, where they consist of coarse quartzose grit passing in places into fine breccia or conglomerate. They dip at a high angle northwards, and, although their actual junction with the Arenig rocks is nowhere visible, there can be little doubt that it is a simple unconformity. Along part of their outcrop, about a mile east of Curraghrevagh hamlet, pale flaggy beds accompanied by grey cherty bands occur at their base. About 1200 feet up in the Mweelrea Grits a band of very coarse conglomerate, with blocks of granite and schist, is seen. This is well exposed on the hillside north-west of Curraghrevagh hamlet.

The coarse grits, displaced by a fault, are also seen underlying the Silurian beds half a mile north-west of Benbeg. A band of pale-yellow felsite, exactly like the band in contact with their base at Curraghrevagh, follows their southern outcrop here.

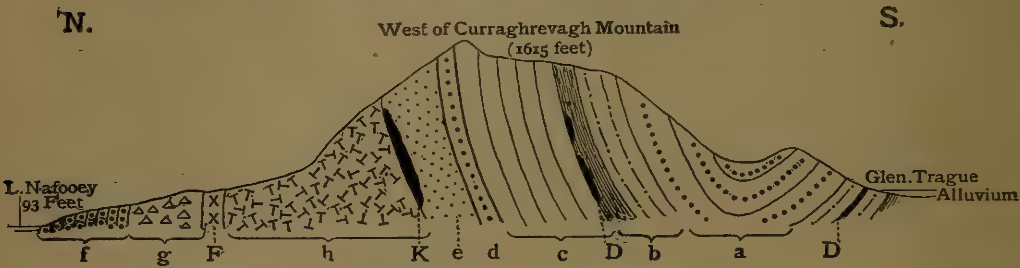
IV. The Silurian Rocks.

The Silurian rocks extend westwards from the Finny River with a uniform west-south-westerly strike, until a point south-west of Bencorragh is reached ($2\frac{1}{4}$ miles). The southerly or south-easterly dip is always high, 60° to 80° in the neighbourhood of Drin; while south-east of Bencorragh the rocks are often vertical, or even slightly overfolded. South-west of Bencorragh they are broken through by one important, and by two minor, cross-faults, which shift their outcrop some 500 yards northwards. They then strike nearly due east and west for about $1\frac{3}{4}$ miles, until, at a point north of the top of Benbeg, they are faulted again to the south, and their strike once more swings round to the west-south-west.

In the eastern part of the area the Silurian rocks form the top of the ridge; but their strike is such that they cross the ridge about half a mile east of Bencorragh, which, together with all the high ground for some distance eastwards and westwards, is formed of spilitic lavas. West of the fault, which shifts their outcrop to the north, the Silurian rocks again form the top of the ridge; and, as they are finely exposed, and are tilted up until they are vertical or dip at angles of 80° or more southwards, it is easy to ascertain the thickness of the various bands.

In the eastern part of the Lough Nafooey area all the Silurian rocks exposed have a southerly dip; but, as one passes westwards, the rocks along the southern border of the map are seen to be dipping at a high angle to the north. The Silurian rocks are therefore folded into a sharp syncline (see fig. 2, below), the northern limb of which forms the main outcrop of the Silurian rocks throughout both the Kilbride and the Lough Nafooey areas, while the southern limb is seen only in the south-western part of the Lough Nafooey area, and, as described in our Kilbride paper,[1] in the north-eastern part of the Kilbride area.

Fig. 2.—*Section along the line AB in the map (Pl. XVII).*



[Horizontal scale: 3 inches=1 mile. Vertical scale exaggerated.]

a=Doon Rock Grits (Wenlock Series).
b=Grey-green flags and purple sandy shales (Tarannon Series).
c=Calcareous Flags (Finny School Beds). } Llandovery Series.
d=Annelid Grits. } Llandovery Series.
e=Red Sandstones. } Llandovery Series.
f=Mweelrea Grits (Llandeilo Series).
g=Tuff. } Arenig Series.
h=Spilite. } Arenig Series.
F=Felsite intrusion.
K=Bostonite intrusion.
D=Dolerite intrusions.

The Silurian rocks may be subdivided almost precisely as in the Kilbride area, namely:—

		Thickness in feet.	
6.	Doon Rock Grits	875 seen.	WENLOCK.
5 *b*.	Grey-green flags	225	TARANNON.
5 *a*.	Purple sandy shales	80	TARANNON.
4.	Finny School Beds (Calcareous Flags)	420 to 820	UPPER LLANDOVERY.
3.	Annelid Grits	90 to 200	UPPER LLANDOVERY.
2.	Red Sandstones	200 to 350	UPPER LLANDOVERY.
1.	Basal Conglomerate	0 to 25	UPPER LLANDOVERY.

A brief description of these beds will suffice:—

(1) The Basal Conglomerate.—Owing probably to imperfection of exposures, we have seen this rock only in the extreme western part of the area—principally in the beds of the two westerly streams which descend from the cirque north of Benbeg, and flow down to Curraghrevagh village. In these streams are two bands of conglomerate, the lower of which is about 25 feet thick. The relations of the rocks here are rather puzzling, and we describe them in greater detail (see p. 113) when dealing with the lime-

[1] Q. J. G. S. vol. lxviii (1912) p. 87.

bostonite intrusion. The pebbles of the conglomerate are chiefly of pink quartzite, with some of felsite and, it is interesting to note, of a rock closely resembling the adjacent bostonite. The conglomerate is shown in our map (Pl. XVII) only where it was actually observed; it probably has a wider extension, but is concealed by peat.

(2) The Red Sandstone.—This is identical in lithological character with the Red Sandstone of Kilbride, which it resembles also in having yielded no fossils. To the south-west of Bencorragh, on the hillside and in the stream-bed, it contains a thin band or bands of purple sandy shale, similar to that forming Band 5 *a* of the above table. Some 15 feet of this shale, passing up into flaggy beds, are seen in a stream-section a quarter of a mile west-south-west of the top of Curraghrevagh.

The lithological resemblance between this red sandstone and shale and the Salrock Beds of Ludlow age in the Leenane area is probably the reason why the former were coloured as Ludlow Beds in the Geological Survey maps.

(3) The Annelid Grits.—These rocks are well exposed near Drin, and for some distance along the ridge to the west the peculiar worm-tubes which they contain are much in evidence. Farther west the worm-tubes are not seen, none having been noticed to the west of Bencorragh. In the western part of the outcrop the Annelid Grits thin considerably, become more thinly-bedded and flaggy in character, and include a marked development of quartz-conglomerate: this does not form a continuous band, but occurs in patches. In the stream running southwards from the col west of Bencorragh, these grits are about 90 feet thick.

(4) The Finny School Beds (Calcareous Flags).—These beds, which reach a thickness of some 820 feet on Curraghrevagh, are of exactly the same character as those at Kilbride, and are very fossiliferous in places, especially at Drin. Like most of the Silurian deposits the Finny School Beds decrease in thickness when followed westwards. A list of the fossils found in these beds at Kilbride appears on p. 86 of our former paper. We found no additional species in the Lough Nafooey area.

(5 *a*) The Purple Sandy Shales (Tarannon).—These form a well-marked band traceable throughout the whole Lough Nafooey area, and seem to maintain everywhere much the same thickness—about 80 feet, as in the Kilbride area.

(5 *b*) The Grey-Green Flags (Tarannon).—South-west of the top of Curraghrevagh pale-grey or green flaggy beds, reaching a thickness of 225 feet, are seen between the Purple Sandy Shales and the Doon Rock Grits. They yielded there *Monograptus priodon* Bronn and *M. galaensis* Lapw., kindly identified by Miss G. L. Elles, D.Sc., who remarks that the *M. priodon* is not the stiff, wide Wenlock form, and that the occurrence of *M. galaensis* is in accord with the field-evidence as to the probable

Tarannon age of these beds. Similar grey flags have been observed to overlie the Purple Sandy Shales at several points along the line of outcrop eastwards, and they probably form a continuous band; but we have not sufficient evidence to show them on the map (Pl. XVII), in which they are coloured with the Doon Rock Grits.

(6) The Doon Rock Grits (Wenlock).—These massive grits occupy the whole of the southern part of the map. In the Kilbride area they were proved by the contained graptolites to be of Wenlock age. In the Lough Nafooey area obscure traces of graptolites have been found in the western part of Glentrague, but these specimens, which did not admit of identification, were the only fossils found in these grits.

V. Field-Relations of the Intrusive Igneous Rocks.

(*a*) The Felsites.

No masses of felsite occur, comparable in size with those of the Tourmakeady, Glensaul, and Kilbride areas, and the rocks with conspicuous well-terminated quartz-crystals, so characteristic of the large intrusive masses of these areas, are almost completely absent.

As in the Kilbride area, no felsite intrusions penetrate the Silurian rocks, and throughout the whole area, except near Curraghrevagh hamlet, and on the hillside two-thirds of a mile away to the south, the felsites are confined to the Arenig rocks. On the hillside west of the hamlet, however, outside the boundary of our map, a felsite-sill occurs in the Mweelrea Grits; while a second intrusion follows the boundary between the Arenig and Llandeilo rocks on the left bank of the Curraghrevagh stream; and a third occurs along the northern face of the ridge extending westwards from near Benbeg, separating the Llandeilo grits from the bostonite-sill at the base of the Silurian. These intrusions are clearly of post-Llandeilo age. We believe, too, that the big intrusion south of Curraghrevagh hamlet is of post-Silurian age, as it is unaffected by a fault which shifts the Silurian deposits. This last-mentioned felsite-mass is the largest in the area, the next largest occurring about $2\frac{1}{2}$ miles away to the east, on the southern slope of Two-Stream Valley. About eighteen other intrusions of felsite, none of them of any great size, have been found penetrating the spilite.

(*b*) The Labradorite-Porphyrite.

This rock occurs associated with bostonite, forming intrusions along the line of unconformity between the Silurian and the Arenig rocks. Only two intrusions were found. One, half a mile east of Bencorragh, is about 400 yards long, and occurs between the bostonite and the spilite. The other, about half a mile west-south-west of the former, seems to cut across the bostonite, so as to appear at its western end between the Silurian rocks and the bostonite, and at its eastern end between the Arenig spilite and the bostonite. This intrusion has a surface-length of about 250 yards.

(*c*) The Lime-Bostonite.

As in the Kilbride area, this rock forms a sill at the base of the Llandovery Beds, whether they rest on the Arenig rocks, as they do throughout by far the greater part of the area, or on the Mweelrea Grits (Llandeilo), as is the case at the extreme western end. In the Lough Nafooey area, in addition to the main intrusive sill, there are three minor dykes of this rock occurring in the Arenig spilite.

The bostonite is very constant in character along its whole outcrop, being very fine-grained, of a dark purple colour, and without obvious phenocrysts. While as a rule devoid of vesicles, it sometimes becomes highly amygdaloidal. The thickness varies considerably, but is on the whole far less than in the Kilbride area, being frequently only some 30 feet. There is progressive diminution in thickness as the rock is followed from east to west, and both north-east and north-west of the top of Curraghrevagh occur tracts where the bostonite is absent. On the other hand, it locally thickens to 80 feet, as in the bed of one of the streams flowing down from the cirque north of Benbeg. These streams afford an interesting and puzzling series of sections, and merit a somewhat detailed description.

The westernmost stream (A on the map, Pl. XVII) shows no exposure below the conglomeratic base of the red sandstone.

The main stream (B) shows the succession of exposures as seen in fig. 3, p. 114. There are two cascades the lower of which is over bostonite, resting upon an ill-defined gritty rock, and overlain by red sandstone with a conglomeratic base. Above this red sandstone comes a second band of bostonite overlain by a thick conglomerate, with patches of shale at the base. This conglomerate forms a relatively level tract of which the footpath crossing the stream takes advantage, and above it is a thick series of red sandstones over which the main cascade falls. The occurrence of two bands of bostonite might be explained as a case of the bifurcation of an intrusion, but as each band of bostonite is succeeded by conglomerate and red sandstone, it seems more probable that the repetition is due to a fault (see fig. 3).

Stream C.—Here red sandstone without any conglomerate at the base rests upon bostonite, below which is an ill-defined gritty rock succeeded by a small dolerite-dyke. In the map (Pl. XVII) these ill-defined gritty rocks in streams B and C are coloured as spilite.

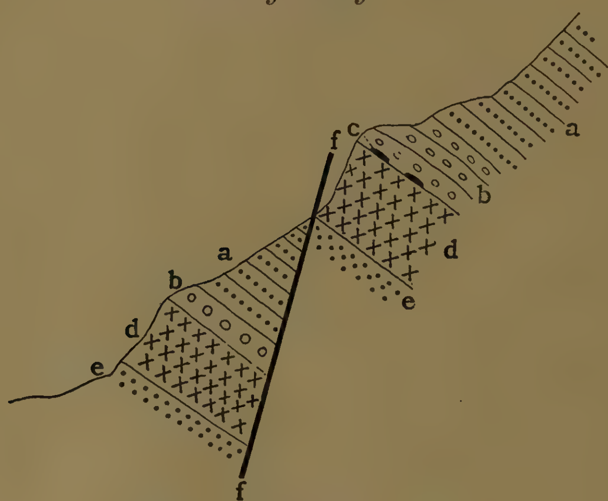
Finally, stream D, for some 40 yards above its junction with stream C, exposes felsite: then, after a gap, comes a curious rock which at first sight resembles a conglomerate. The 'pebbles' are, however, all red felsite, and it appears that the entire rock is really a much-crushed and weathered felsite. The upper part includes patches of very pyritous black shale and black chert. A band of bostonite about 80 feet thick follows, succeeded by red sandstone. A short distance east of this stream a fault brings on spilite. To this fault may be attributed, not only the crushed character of

the felsite, but possibly also the apparent thickness of the bostonite which may be swung round by the fault. As the big felsite-mass south of Curraghrevagh hamlet is unaffected by this fault, it is probably a post-Silurian intrusion.

Taking the Lough Nafooey and Kilbride areas together, the bostonite-sill has been traced almost continuously for a distance of 7 miles. How much farther it extends is unknown, but it is seen on the northern shore of Derry Bay, half a mile from its outcrop at the eastern end of the Kilbride peninsula.

A second considerable intrusion of lime-bostonite occurs as a dyke in the spilite to the south-west of the top of Bencorragh, having a length of about three-quarters of a mile. The eastern part lies parallel to the main sill; but the western part diverges

Fig. 3.—*Section in Stream B, flowing down from Benbeg to Curraghrevagh hamlet.*



[Scale: 1 inch = about 100 feet.]

a=Red Sandstone. b=Conglomerate. c=Patches of black pyritous shale. d=Bostonite. e=Gritty rock. f=Fault.

northwards, and is penetrated by two small dolerite-dykes. North of the little tarn at the col between the Bencorragh and Curraghrevagh ridges, two smaller intrusions in spilite occur, trending respectively a little to the east and a little to the west of north.

(*d*) The Dolerites.

The dolerite-intrusions include (*a*) augite-dolerites devoid of mica, and (*b*) mica-dolerites.

The augite-dolerites occur as dykes in the spilites. They tend to weather to the same dark-brown colour as the spilites, and are in consequence often difficult to recognize in the field.

In the Kilbride area mica-dolerites were generally found intrusive in the Finny School Beds. In the Lough Nafooey area they mainly occur in the overlying Purple Sandy Shale. For the first

$1\frac{3}{4}$ miles, as one follows the outcrop of this band westwards from the Finny River, no dolerites are seen. South and south-west of Bencorragh five small dykes occur either in, or in contact with, the Purple Shale. To the west of the big fault which shifts the Silurian outcrop northwards, these dykes become still more numerous, probably at least a dozen occurring between this fault and the one north of Benbeg. At several points the Purple Shales are much baked by these intrusions. Mica-dolerites are not, however, confined to the Purple Shale; thus a good example occurs in the grey shales underlying the Doon Rock Grits near the southern border of our map, half a mile east of Benbeg, and another in breccia west of the Finny River.

VI. Petrographical Details.

(*a*) The Felsites.

The felsites resemble very closely those of Kilbride, especially in the strong corrosion of the quartz-crystals and the frequent association of plagioclase (albite) with orthoclase. Pseudomorphs after pyroxene are, however, less characteristic. In many rocks the ground-mass is wholly or partly spherulitic. In one case (60) remarkable micropegmatitic groups representing twinned felspar occur. Three samples of felsite had an average specific gravity of 2·64.

(*b*) The Lime-Bostonite.

Some of the lime-bostonites differ from those of the Kilbride area in their relative richness in quartz. This is especially marked in the case of the oblique dyke south-west of the top of Bencorragh, as the marginal part includes abundant quartz-phenocrysts which have not been found in any other lime-bostonite from Kilbride or Lough Nafooey. Three samples of bostonite had an average specific gravity of 2·65.

(*c*) The Labradorite-Porphyrite.

We have nothing to add to the description of this rock given in our Kilbride paper.

(*d*) The Dolerites.

These closely resemble the corresponding rocks from Kilbride, especially in the prevalence of mica-dolerites. Certain of the mica-dolerites (35), however, are exceptional in containing numerous crystals of hornblende. The augite is sometimes fresh, sometimes represented by pseudomorphs in carbonates; it may occur in well-formed crystals or in ophitic plates. No olivine was met with.

The development of carbonates along the cleavage-planes of the mica is characteristic. Eleven samples of augite-dolerite had an average specific gravity of 2·81; one specimen of mica-dolerite gave 2·80.

(e) The Spilites (Pillow-Lavas).

At certain localities, particularly in the neighbourhood of Curraghrevagh hamlet, the spilite becomes coarsely porphyritic with abundant large albites. Dr. Flett, to whom we showed these rocks, compared them with those from the Plymouth and Newton Abbot neighbourhood.[1] The only other point to add to the description of these rocks given in the Kilbride paper, is the prevalence, especially near the top of Bencorragh, of vesicles filled with epidote or partly with epidote and partly with quartz. The average specific gravity of eight examples of spilite was 2·74.

VII. Comparison of the Rocks of the Kilbride, Lough-Nafooey, and Killary Areas; and Conclusions.

Although no fossils except radiolaria were found associated with the spilites and cherts of the Lough Nafooey area, there can be no doubt that these rocks are the same series as those of the Kilbride area, which are associated with black cherts and slates containing *Didymograptus extensus*, and are therefore of Middle Arenig age. No igneous rocks of Middle Arenig age were described by Mr. Maufe and Mr. Carruthers from the Killary area, but they obtained an abundant series of Middle Arenig graptolites in a bed of black shale and chert at Bencraff, 6 miles west of Lough Nafooey.

Limestone-breccias so characteristic of the Tourmakeady and Glensaul areas, but completely absent at Kilbride, are met with again at Lough Nafooey and in the Killary district. At Glensaul they are associated with grits and other deposits containing Upper Arenig fossils (*D.-hirundo* Zone). At Killary, too, they are associated with strata considered to be of Upper Arenig age—the Leenane and Rossroe Grits.

The Silurian rocks of the Kilbride area all extend across into the Lough Nafooey area; and though, as their outcrop is followed, certain differences in thickness and lithology are noticeable, the general resemblance of the successive beds throughout the whole extent of the outcrop is so great as to amount to identity.

The Killary and Lough Nafooey rocks, on the other hand, contrast somewhat strongly. The thick Red Sandstones and overlying Annelid Grits of the Lough Nafooey area are unrepresented in the Killary area. The next succeeding beds in both areas are similar, consisting principally of calcareous strata with abundant Llandovery fossils. In both areas these calcareous strata are followed by thick arenaceous beds; in the Lough Nafooey area there are grits overlying flaggy beds containing Tarannon fossils, while in the Killary area grits with Wenlock fossils overlie a coarse conglomerate.

The highest beds in the Killary area, the Salrock Beds of Ludlow age, are unrepresented in the Lough Nafooey area.

The Kilbride and Lough Nafooey areas agree very closely in regard to the intrusive rocks—felsites, lime-bostonites, coarse porphyrites, and dolerites. The felsites do not, however, occur in such

[1] See 'Geology of the Country around Plymouth & Liskeard' Mem. Geol. Surv. Expl. Sheet 348 (1907) pp. 95–97 & pl. iv, fig. 1.

Table comparing the Rocks of the Kilbride, Lough Nafooey, and Killary Areas.

	Kilbride.	Lough Nafooey.	Killary.
Silurian.			
Ludlow	Unrepresented.	Unrepresented.	Salrock Beds.
Wenlock	Doon Rock Grits, with *Monograptus vomerinus*. 2000 (seen)	Doon Rock Grits. 875 (seen)	Owenduff Series. Thick grits, with *Monograptus vomerinus* and *M. riccartonensis*.
Tarannon	Purple Sandy Shales. 75	Grey Flags with *Monograptus priodon* and *M. galaensis*. 225 Purple Sandy Shales. 80	Owenduff Series. Coarse conglomerate at the base.
Upper Llandovery	Calcareous Flags, with many Upper Llandovery fossils. 600	Calcareous Flags, with many Upper Llandovery fossils. 420–820	Owenduff Series. Calcareous shelly grits with Llandovery fossils, overlying a thin development of red mudstones and barren green grits with breccia at the base.
	Annelid Grits. 900 Red Sandstone, with conglomerate at the base 200–700 resting on Arenig beds.	Annelid Grits. 90–280 Red Sandstone, with impersistent conglomerate at the base 200–350 resting on Arenig and Llandeilo beds.	Unrepresented.
Ordovician.			
Bala and Llandeilo	Coarse grits and conglomerates.	Coarse grit and conglomerate (Mweelrea Grits). No fossils found.	Mweelrea Grits. *Ogygia buchi* found in the lower beds; the series in Formnamore plateau reaches a thickness of 12,000 feet.
Upper Arenig	Unrepresented.	Limestone-breccia, associated with thin tuffs and gritty beds.	Limestone-breccia, Leenane and Rossroe Grits with *Diplograptus dentatus* and other forms.
Middle Arenig	Thick mass of gritty tuff and coarse breccia, associated with extensive flows of spilite, and with cherts and shales containing *Didymograptus extensus* and other fossils.	Enormous mass of spilite, associated with a relatively slight development of tuffs and breccias, and thin cherts and shales. No fossils found, except radiolaria in the cherts.	Black shales and cherts with *Didymograptus extensus*, *Dichograptus*, and other fossils.

[The numerals refer to thicknesses expressed in feet.]

large masses as in the Kilbride area. The relations of the rocks in the Kilbride, Lough Nafooey, and Killary areas are summarized in the appended table (p. 117).

In conclusion we wish to tender our sincere thanks to Miss G. L. Elles, D.Sc., for identifying our graptolites; to Dr. G. J. Hinde, F.R.S., for examining our radiolarian rocks; to Dr. J. S. Flett, F.R.S., for reporting on certain of our igneous rocks; and to Prof. G. A. J. Cole for the gift of 6-inch Ordnance Survey maps.

EXPLANATION OF PLATES XVI AND XVII.

Plate XVI.

Fig. 1. Pillow-lava near the top of Bencorragh.
2. Pillow-lava on the southern slopes of Bencorragh.

Plate XVII.

Geological map of the Lough Nafooey area, on the scale of 6 inches to the mile, or 1 : 10,560.

Discussion.

Mr. E. S. Cobbold asked whether the other areas mentioned agreed with that of Lough Nafooey in having the younger side, so far as the Ordovician rocks were concerned, on the north and west, and the still younger Silurian cover on the south and east.

Dr. J. V. Elsden remarked upon the description of certain of the intrusive igneous rocks, mentioned in the paper, as lime-bostonites. This type of rock was first described in detail by himself, and he had applied to it the term used by Prof. Brögger for the lime-bostonites of Mœna. Other authors had since used different names for this rock, which was, he thought, admitted to be a specific type. Although he attached little importance to its actual designation, he did plead for uniformity of nomenclature, and drew attention to the confusion arising from a want of agreement as to what these rocks should be called. He presumed that the rocks referred to by the Authors resembled those described in their previous papers under the same name.

Prof. Reynolds, in reply to Dr. Elsden, stated that the rocks from Lough Nafooey described as lime-bostonites were identical in character with those from Kilbride. There seemed to be lack of agreement in the use by petrologists of the terms lime-bostonite and keratophyre; the Authors used the former term for an intrusive, and the latter for a contemporaneous, rock.

Mr. Gardiner, in reply, pointed out that the lowest fossiliferous Silurian beds in the Kilbride and Lough Nafooey areas were of Upper Llandovery age, and corresponded to the lowest fossiliferous Silurian deposits in the Killary district. The Arenig rocks lay with the Llandeilo rocks entirely to the north of them, and the Silurian rocks to the south. It was only in the extreme west of the area that the Silurian deposits came to rest upon the Llandeilo grits.

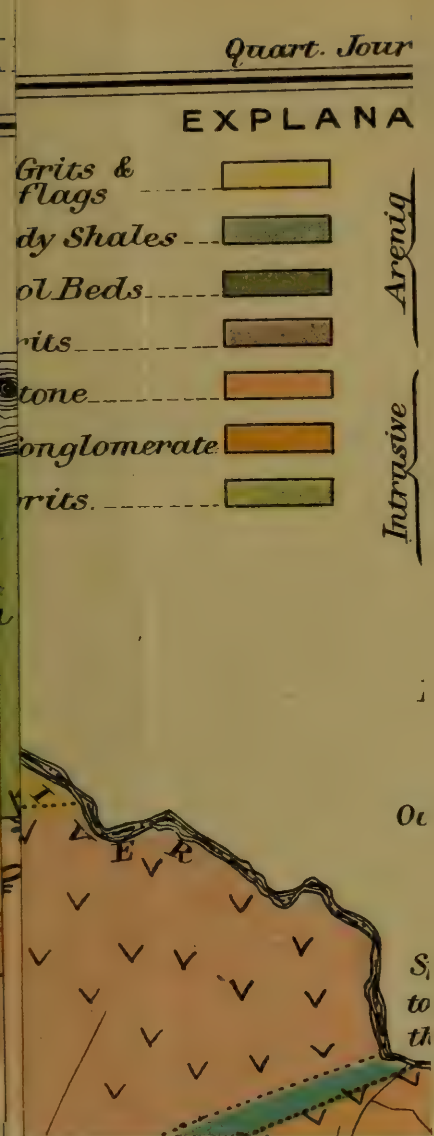
Fig. 1. Pillow-Lava near the top of Bencorragh.

S.H.R., Photo.

Fig. 2. Pillow-Lava on the southern slopes of Bencorragh.

S.H.R., Photo.

Bemrose, Collo Derby



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GEOLOGICAL MAP OF THE LOUGH NAFOOEY AREA.

6. *On the* Occurrence *of a* Giant Dragon-Fly *in the* Radstock Coal Measures. By Herbert Bolton, M.Sc., F.R.S.E., F.G.S., Reader in Palæontology in the University of Bristol. (Read February 4th, 1914.)

[Plates XVIII & XIX.]

Some two years ago, Dr. E. A. Newell Arber drew my attention to a fragment of an insect-wing, lying upon a mass of shale which he had obtained from the Tyning waste-heap at Radstock Colliery (Somerset), and afterwards deposited in the Sedgwick Museum at Cambridge. Unfortunately, the precise horizon from which the shale came cannot be determined, because the waste-material from no fewer than five collieries is thrown upon the Tyning waste-heap, or Tyning Batch.[1]

By the courtesy of Dr. Arber and the Sedgwick Museum authorities, I have been granted the loan of the specimen for the purposes of examination and description.

The fragment consists of the proximal portion only of a wing, and forms, I believe, not more than a third of the complete structure. The wing has also been broken along its length, and a portion of the middle lost. This is apparently caused by the shale splitting irregularly, the shaly surface being more than usually uneven. The anterior and posterior portions of the wing-fragment still retain their normal position relatively one to the other, a condition unlikely to happen if they had drifted separately to the place where they now are. This also bears out the supposition that the breakage is due to fracture of the shale, and that the missing middle part of the wing was upon the portion of shale that is broken away. The length of the wing-fragment along the anterior margin is 64 mm.; the length of the hinder margin is but 53 mm., a portion of the proximal extremity being missing. The greatest breadth of the wing is 40 mm. These measurements are indicative of an unusually large wing, and if, as I suppose, but a third of the whole is present, then the span of wing of the complete insect must have been considerable. No insect-wing of so large a size has hitherto been recorded from this country, and it can only be paralleled by wings obtained from the Coal Measures of Commentry (Allier).

No trace of the body or other parts of the insect can be seen.

The first feature that attracts attention in the wing-fragment, is the presence of four main veins only. This, if it occurred in a complete wing, would be very anomalous, and at once place the insect outside any known group. Six principal veins are generally recognized in the wing of an Orthopteron or Neuropteron, to one

[1] Q. J. G. S. vol. lxvii (1911) p. 322.

or other of which groups this fossil wing is likely to belong. Any principal veins that are lacking must necessarily have occupied the middle area from which the wing-structure is missing. The anterior wing-fragment consists, evidently, of two veins, the costa and sub-costa, the hinder fragment showing clearly the presence of the cubital and anal veins. As the anterior and posterior wing-margins are present, no loss of veins can have occurred, except in the middle of the wing, and it therefore follows that the absent veins are the radius and media. The proximal anterior wing-margin consists, not of a free alar expansion, as is usual in the Protodonata, but of a coriaceous and tuberculate mass which is well marked off from the costa along its whole length. For some time I held the view that this coriaceous bar represented the costa, and that therefore the anterior wing-margin was supported by a united costa and sub-costa, and the next vein formed the radius. This view I do not now consider tenable, but regard the coriaceous bar as an unusual and highly-modified alar area. That other veins existed between the anterior and the posterior pairs is proved by traces of vein-fragments in the middle area, but so broken up and fragmentary as to be almost unrecognizable.

The traces consist of three short portions of a single vein lying in the middle line. These vein-traces are too small, and too far back, to have formed any part of the stem of the radius, but might well have been portions of secondary branching, or even of the media. Assuming that the radius and the media occupied the middle position to which I have assigned them, and that the obscure remnants of a vein are portions of one of these veins, the wing resolves itself into a more intelligible structure. At the same time, its likeness to forms belonging to the Protodonata becomes very evident. This fact is well borne out by a direct comparison of the wing-fragment with the corresponding portion of *Meganeura monyi* Brongn. Other Protodonate features also become clearly evident: namely, the parallelism of the principal veins, the co-existence of similar cross-veins, and the distinctive character of the anal areas in the two wings. So closely does the proximal part of the wing of *M. monyi* agree with the Radstock fragment, that there can be little doubt of some close degree of relationship. It is, therefore, on the assumption that it is a Meganeurid wing that I proceed to describe the general character of the Radstock specimen.

Description.

The extreme proximal portion of the anterior margin of the wing is swollen out into an elongated tubercular mass, which thins out distally, dying away imperceptibly along the anterior margin.

It can be traced quite easily over a length of 20 mm.; near the articulation of the wing it is covered with numerous low, smooth-topped tubercles irregularly arranged. The extreme free margin shows up in one place as a flat, straight, knife-like edge, crossed by a series of fine striations directed antero-posteriorly. This

tubercular structure I regard as the equivalent of the free alar expansion seen in front of the costal vein in *Meganeura monyi*. It forms a rigid bar, enormously strengthening the anterior wing-margin, and rising proximally into a prominent shoulder. The costa is sharply marked off from the hinder margin of the tuberculated alar mass, and passes directly outwards as a broad strap-shaped vein, broadest at its point of origin, and very slowly diminishing in width as it passes outwards towards the tip of the wing. It must have formed the greater part of the frontal margin of the wing. At its articular origin the costa seems united to the next vein (sub-costa) by a common root, but examination shows that this apparent union is caused by a slight backward movement of the proximal end of the costa over that of the sub-costa, and that the two may have been quite free one from the other. Some distance beyond the termination of the alar mass the free margin of the costa gives origin at regular intervals to a series of low spines, projecting freely from the front edge of the wing, and gradually inclining outwards towards the wing-apex. A few scattered tubercles and a faint ridge occur along the middle line of the vein and eventually die out, leaving the distal portion of the costa smooth—except for the marginal spines. The hinder edge of the costa is straight, and interrupted along its course by a series of parallel branches, which pass directly backwards and join the sub-costa. Of these lateral branches eleven are still whole and clearly marked, while portions of nine others can be distinguished. It would, therefore, appear that the two veins were joined along their whole length by a parallel system of straight cross-branches with no intervening network. Several of these cross-branches seem to be jointed at their anterior third.

The sub-costa arises in close contact with the costa, diverging rapidly until the two are about 56 mm. apart. Once the maximum divergence has been attained, the sub-costa remains fairly parallel to the costal margin, although there are indications that the two come together some distance beyond the edge of the wing-fragment.

This is mainly brought about by the long flattened convexity of the costal margin. The costa and sub-costa are nowhere more than 5 to 6 mm. apart, in the main but 4 mm., the interval narrowing down to 3 mm. at the broken distal edge of the wing. While the sub-costa possesses the flat strap-shaped character of the costa, it is, on the whole, a more delicate and slightly narrower vein. A few tubercles are disposed in an irregular median line along its length.

Nowhere along the hinder margin of the sub-costa can be traced any portion of the general integument of the wing; the only indication of a backward continuation is seen in the ragged edge of the proximal portion of the vein, and in traces of a few branch veins passing directly backwards.

Radius and media.—I have already given reasons for supposing that the intermediate venation of the wing is missing, and that in all probability this venation consisted of the radius and the media with all their branchings.

The character of the radius and the media can only, therefore, be assumed by reference to what obtains in the wing of allied Protodonata, such as *Meganeura monyi* and *M. selysii*.

In these forms a complex of principal veins arises from one or two roots between the sub-costa and the cubitus. In the case of *M. monyi*, this complex arises from a relatively-stout radius and a closely-applied very thin media. In *M. selysii*, it would seem that the complex arises from a joint radius-media trunk.

The vein-complex occupies almost the whole of the distal two-thirds of the wing in both species of *Meganeura*. Of its presence in the Radstock wing-fragment there is no trace, except the detached fragments already mentioned. In the restoration which I have attempted (Pl. XIX, fig. 3) it will be seen that the vein-fragments appear as parts of the media, the radius being wholly missing.

Cubitus.—This vein is separated from the sub-costa by an interval formerly occupied by the radius and the media: this interval varies between 5 and 10 mm. The cubitus is a strong flattened vein giving off an oblique branch from its hinder border, then curving forwards, and finally backwards as it pursues its course outwards.

Its general direction is such as to lead to the inference that it curved backwards into the hinder wing-margin, probably reaching it, about the end of the middle third of the wing. The most proximal portion of the vein has been broken away; its course may probably be indicated by a faint line passing forwards in the direction of the bases of the sub-costa and costa. The outer of the two backward curves of the cubitus is the greater, and so a relatively wide interval lies between the cubitus and the hinder margin of the sub-costa. This accords precisely with what obtains in the same region in *Meganeura monyi*, and is undoubtedly caused by the beginning of the vein-complex of the radius and media, which lay between the two.

The oblique proximal branch of the cubitus, to which I have already referred, is a deeply-incised and stout vein which passes backwards until it joins with the anal vein. It has the appearance of an important commissure between the cubitus and the anal, or of a posterior branch of the former which has fused with the latter.

Beyond the commissure, the cubitus is joined to the anal by a system of parallel slightly-curved branches, similar in character to those which unite the sub-costa with the costa. No fewer than twenty-five of these branches can be distinguished. Inward of the commissure are two similar transverse branches, a little more curved than the remainder. As in the costa and sub-costa, a median line of tubercular ornament is present.

Anal.—The fourth of the strongly-marked veins is the anal. Its course is somewhat similar to that of the cubitus; but the proximal backward curve is longer and flatter than in that vein, so that its forward-directed middle portion lies opposite to the second

backward curve of the cubitus: as a result, the two veins are somewhat widely separated proximally, and distally approach each other closely. The anal is, in this wing, a powerful vein, and certainly occupied more than half of the hinder wing-margin.

The anal gives origin along the whole length of its hinder margin to a series of branches, which arise at slightly increasing intervals, being closest proximally and most widely separated between the twelfth and thirteenth branches, beyond which the interspaces narrow up to the origin of the fifteenth branch. These branches, proximally, pass in straight, or slightly oblique, lines backwards to the wing-margin. Farther out they become curved, the convexity being towards the wing-apex. The twelfth branch is a strong and important vein, which sweeps in a powerful double curve outwards and backwards to the wing-margin. It corresponds in position to Brongniart's 'Vein X.' Beyond it are the remains of three feebler veins, which bend in a simple curve to the margin. The spaces between the branches are divided up into a series of quadrangular areas or cellules, by a great series of secondary rami arising at right angles to the branches. The twelfth branch, which stands out by reason of its robust character and sweeping curve, gives off, in its inner side, a series of rami which divide and separate so widely that at first a double, and then, near the wing-margin, a treble series of cellules are enclosed between them. On its outer or distal side, it cuts off a series of five branches arising from the hinder border of the main stem of the anal, the enclosed quadrangular areas being increasingly elongated antero-posteriorly up to the eighteenth branch, the course of which is not interrupted by that of the twelfth.

'Vein X' of Brongniart.—The cellules enclosed in the anal area by this vein show a tendency to irregularity, both in size and in form, much in excess of the irregularity noted in *Meganeura monyi*, and those cellules which lie along the hinder wing-margin are longer than wide.

The integument in many of the quadrangular cellules is marked by a slight central elevation, which, under high magnification, presents the appearance of a circular thickened lip, with a central depression or perforation. These structures are marked by no regularity of disposition, but are most numerous on each side of the twelfth branch of the anal. The integument within the cellules is, in some instances, obliquely wrinkled. The hinder wing-margin is almost straight, well defined, and spinous along the whole or a great part of its length. The spines are low, directed outwards, and in general character somewhat similar to those that occur in the anterior margin of the wing. They are not so clearly shown, however, and it is doubtful whether they are truly marginal, or whether the integument stretches a little beyond them: I incline to the latter view. The wing-fragment appears to lie with the ventral surface uppermost. It is, therefore, a proximal fragment of a right wing.

Affinities.—The broad longitudinal principal veins, with their straight cross-branches, and the characters of the anal area form typical Protodonate features, and there can be little doubt that the wing belongs to a member of that group. Its relationship seems closest to the genera *Paralogus* and *Meganeura*. The genus *Paralogus* of Scudder contains but one species—*P. æschnoides*.[1] The specimen upon which the species was founded is incomplete, the tip of the wing being missing. It was restored by Scudder, who gave a maximum length of 125 mm. to the complete wing. This implies a much smaller insect than that to which the Radstock wing-fragment belonged.

A comparison of the Radstock wing-fragment with the proximal third of *Paralogus æschnoides* shows that there is a general similarity, but a wide difference in detail. *P. æschnoides* does not possess a free alar expansion on the anterior margin of the wing, nor is there any trace of tubercular ornament. The costa and the sub-costa are more widely separated than in the Radstock wing, the sub-costa reaching the wing-margin beyond the middle of the length of the wing.

The cross-branching of the smaller veins is much the same in the two wings. The main points of difference are the presence in the Radstock specimen of tubercles along the main veins; the remarkably robust character of the latter; also the development of marginal spines, and of a frontal coriaceous bar. It is, however, with the members of the remarkable family Meganeuridæ that the Radstock wing-fragment seems to have the closest relationship.

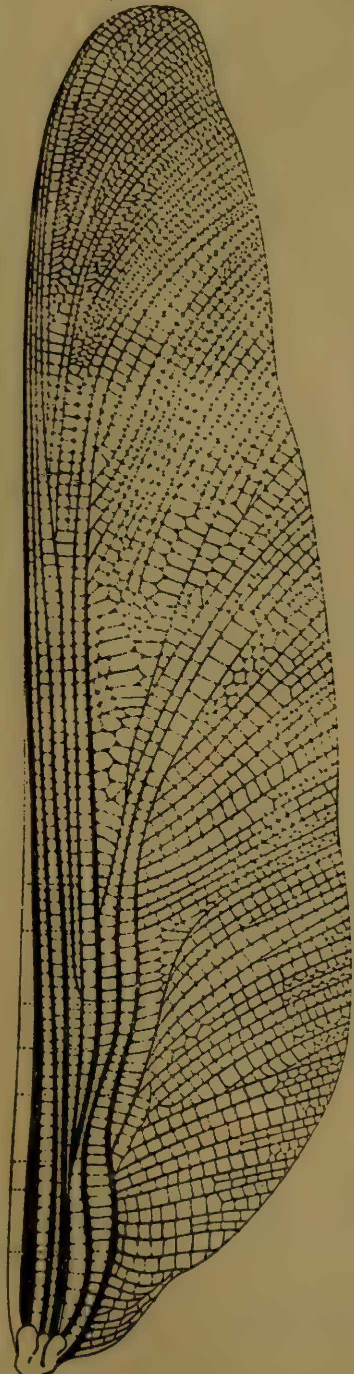
Meganeura monyi, the huge dragon-fly described by Brongniart[2] from the Stephanian of Commentry, possesses a powerful costal vein, which does not reach the frontal margin until the middle of the wing—the inner half of the frontal margin being occupied by a free alar development of the wing-integument. This alar area occupies the position which, in the Radstock specimen, is occupied by the coriaceous tubercular bar. The costal vein in both is a broad and powerful strap-shaped structure, which undoubtedly reached to the wing-apex in the Radstock wing, and is known to do so in *M. monyi*. In both wings the costa is separated by a slight interval from a somewhat parallel and weaker vein, the sub-costa. The sub-costa is a much weaker vein in *M. monyi* than in the Radstock specimen, where it is little inferior in development to the costa itself.

The hinder pair of veins in the Radstock wing correspond very closely indeed to Brongniart's 'Veins VIII & IX'; the twelfth branch of the hinder vein in the Radstock wing also corresponds to 'Vein X' of Brongniart. In detailed structure the two wings differ markedly. There is no evidence of anterior and posterior spines in *Meganeura monyi*, nor of the extensive tuberculations

[1] 'Insect Fauna of the Rhode Island Coalfield' Bull. U.S. Geol. Surv. No. 101 (1893) p. 21.

[2] 'Faune Entomol. Terr. Prim.' 1893, p. 521, & pl. xli, figs. 1, 4; also C. R. Acad. Sci. Paris, vol. xcviii (1884) p. 833.

seen upon the principal veins in the Radstock wing. *M. monyi* is also a wider wing, with only one trace of elongated cellules along the proximal hinder margin, and no areolæ are present in the cellules around 'Vein X.' These differences are scarcely generic, and I see no reason why the wing should not be classed as Meganeurid.



Reproduction of Brongniart's figure of the forewing of Meganeura monyi.[1] *Half of the natural size.*

It is possible, perhaps, to regard the frontal tubercular bar not as a modified alar area, but as a highly-modified costa, closely attached to the sub-costa along its whole length. If such a view be taken, the second principal vein would be the radius, and the media and the vein-complex developed from it would alone be absent.

Such a view I had once taken, but have abandoned in favour of that already set forth. Considered as a Meganeurid wing, the Radstock specimen is no primitive structure, but a highly-modified wing, in which a secondary development of spines and tubercles is a strong feature. In the absence of the hinder wing, it is not possible to determine whether the marginal spines upon the inner border served for interlocking the two wings during flight, but some such function appears to be suggested by the evidence.

Even if it should be considered that the difference which separated the Radstock specimen from *Meganeura monyi* was of generic rank, the fragmentary character of the specimen, and my consequent inability to determine all possible generic characters, causes me to place the specimen provisionally in the genus *Meganeura*, and as a new species—to which I attach the name of *radstockensis*.

The specific characters are the presence of a tubercular and

[1] 'Insectes Fossiles des Temps Primaires' 1893, pl. xlii (26) fig. 2.

coriaceous frontal marginal bar to the costa, the presence of spines upon the frontal and hinder margins, and the occurrence of an oblique commissure uniting the cubital and anal veins.

Horizon.—Upper Coal Measures, Radstock (Somerset).

Dimensions.—The dimensions of the wing-fragment have already been stated, and a reconstruction of the whole insect—based upon that of *Meganeura monyi*—gives the insect a total wing-length of $7\frac{1}{2}$ inches.

Allowing a width of 1 inch for the diameter of the thorax, the whole wing-span of *Meganeura radstockensis* would not have been less than 16 inches. This is about 8 inches less than the wing-span of *M. monyi*.

I desire to express my indebtedness to Mr. J. W. Tutcher, for the skill with which he has photographed the wing-fragment; and to Mr. R. E. J. Bush, for the drawing of the restored outline of the wing.

EXPLANATION OF PLATES XVIII AND XIX.

Plate XVIII.

Fig. 1. Photograph of the wing-fragment, showing the positions of the anterior and posterior pieces, and the area formerly occupied by the radius and media. Enlarged × 1·3.

2. Proximal portion of costa and sub-costa, showing the tubercular anterior edge, and the backward slipping of the costa over the sub-costa. Enlarged × 4.

3. Distal portion of the costa and sub-costa, showing the spinous anterior border of the former, the cross-branches uniting the two veins, and a median line of tubercular ornament upon the sub-costa. Enlarged × 4.

Plate XIX.

Fig. 1. Proximal portion of the inner margin, showing the development of stout submarginal spines. Enlarged × 4.

2. More distal portion of the inner margin, showing the submarginal spines. Enlarged × 4.

3. Restoration of the wing of *Meganeura radstockensis*, upon the lines of *M. monyi*. Half of the natural size.

Discussion.

The President (Dr. A. Strahan) complimented the Author on a most interesting and detailed piece of work, and commented on the extreme beauty of the photographs by which the communication was illustrated.

Mr. G. W. Young congratulated the Author on a very delicate and successful investigation, and regretted that such papers were not more frequently presented to the Society. It seemed to him almost incredible that objects of such extreme tenuity as dragon-flies' wings could ever be preserved so perfectly as the specimen shown. He doubted that the spines of the fore edge of the hind-

FIG. I. WING FRAGMENT. × 1·3

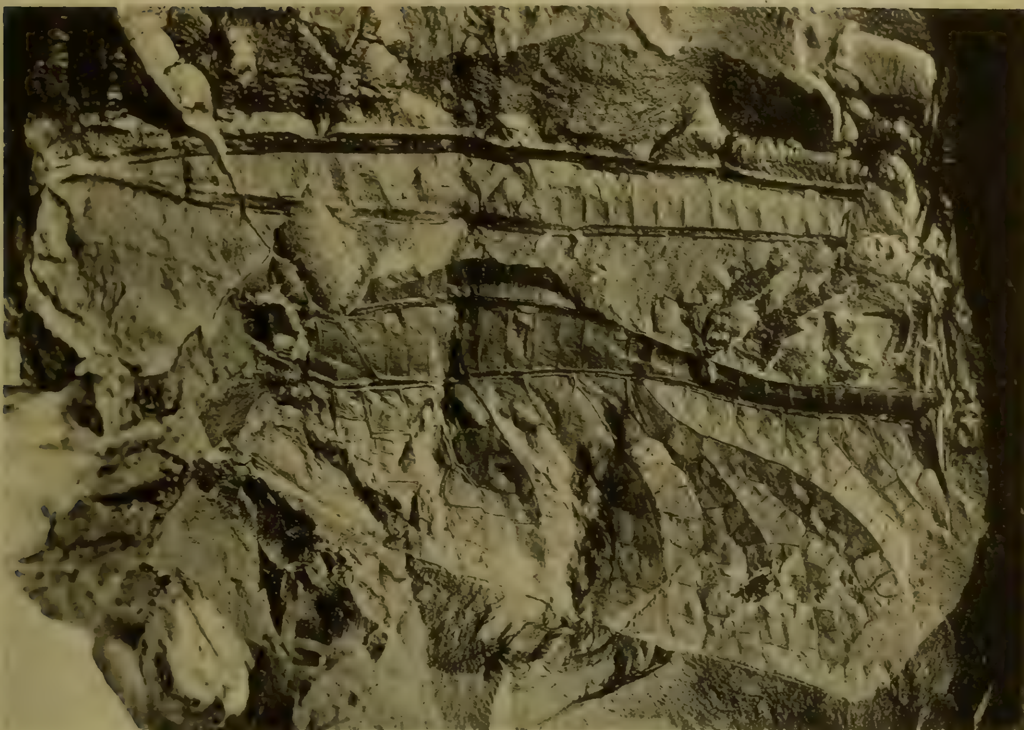


FIG. 2. PROXIMAL PORTION OF COSTA AND SUB-COSTA.

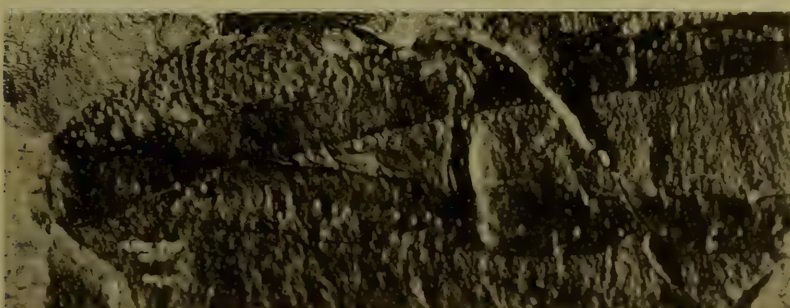


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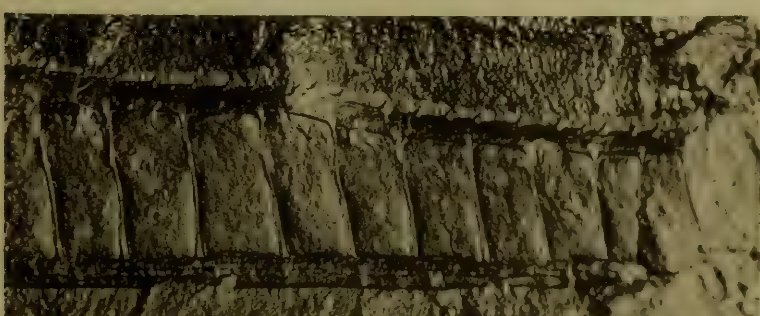
FIG. 3. DISTAL PORTION OF COSTA AND SUB-COSTA.



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J. W. Tutcher, Photo.

Bemrose, Collo, Derby.

MEGANEURA RADSTOCKENSIS.

Fig. I. Proximal portion of the inner margin.

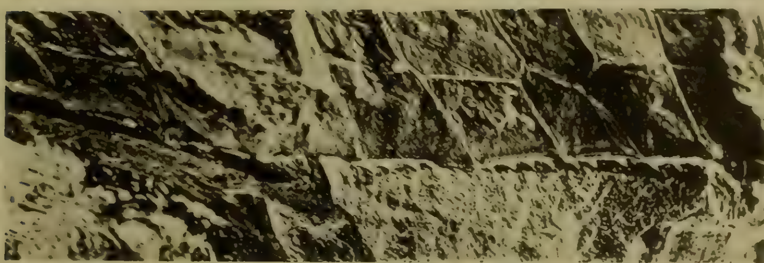

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Fig. 2. More distal portion of the inner margin.

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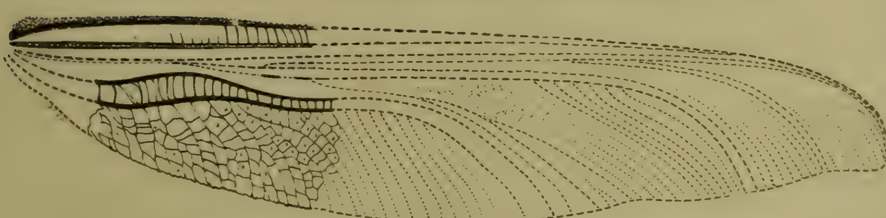
Fig. 3. Restoration of Wing. × ½



J. W. Tutcher, Photo.

Bemrose, Collo., Derby

MEGANEURA RADSTOCKENSIS.

wing acted as hooks to catch on to the hinder margin of the fore-wing, because, so far as he was aware, no recent dragon-fly possessed them, and it was difficult to think that so useful a structure, once acquired, would ever have been lost. If their function was as the Author suggested, he thought that it was not a case of the fore-shadowing of the typical wing of the Hymenoptera, but more probably an instance of homologous evolution.

Mr. E. A. Martin suggested that certain marks between two of the veins were evidence of recent folding, and that the wing was that of a young individual. He referred to the hidden ancestry of this giant dragon-fly, and thought that perhaps after all, in early geological times, evolution did move *per saltum*.

The Author, in reply to Mr. Young, said that, as only a third of the wing was known, it was difficult to decide whether the spines upon the hinder margin served for the interlocking of the two wings, or foreshadowed what is seen in recent Hymenoptera.

In reply to Mr. Martin he stated that, in his opinion, the wing-fragment was that of an adult insect, for he considered that the frontal coriaceous bar upon the costa could hardly have reached so mature a state of development in a young form. He thanked the Fellows present for the kind way in which his paper had been received.

7. *The* Miocene Beds *of the* Victoria Nyanza *and the* Geology *of the* Country *between the* Lake *and the* Kisii Highlands.

By Felix Oswald, D.Sc., B.A., F.G.S. With an Appendix on the Vertebrate Remains, by Charles William Andrews, D.Sc., F.R.S., F.G.S.; and an Appendix on the Non-Marine Mollusca, by Richard Bullen Newton, F.G.S. (Read June 25th, 1913.)

[Plates XX–XXX.]

Contents.

I. Introduction.

In the winter of 1911 I undertook a journey to the Victoria Nyanza on behalf of the British Museum, in order to investigate some beds of Miocene age, discovered in 1909 by Mr. G. R. Chesnaye while prospecting near Karungu on the eastern coast of the lake. He discovered fragments of bones and of Chelonian carapaces in low cliffs capped with basalt, situated a few miles to the south-east of Karungu. Mr. C. W. Hobley, C.M.G., H.M. Provincial Commissioner, who has made important researches in the natural history and anthropology of British East Africa, immediately realized the significance and importance of the discovery, and induced the late Mr. D. B. Pigott, a Government official, to undertake a search for further specimens. As the result of his efforts, he forwarded to Mr. Hobley a portion of the left ramus of the mandible, some teeth, and the patella and calcaneum of a *Dinotherium*, together with fragmentary remains indicating the presence of a small Rhinoceros *(Aceratherium)*, *Trionyx*, *Testudo*, and some Crocodilian remains.

Mr. Hobley presented these fossils to the British Museum, and Dr. C. W. Andrews, F.R.S., described and figured the remains of the *Dinotherium*, which he named *D. hobleyi*, in the Proceedings of the Zoological Society for 1911 (pp. 943–45 & pl. xlviii),

regarding the species as very similar to *D. cuvieri* Kaup, of the Lower and Middle Miocene of France, especially characteristic of the Burdigalian horizon.

Unfortunately, nothing was known of the circumstances of the discovery, for Mr. Pigott was shortly afterwards killed by crocodiles, when his raft was upset by a hippopotamus that he had wounded. Accordingly, I offered to utilize my leave by going out to Africa, in order to make a thorough investigation of the locality and to collect specimens for the British Museum.[1]

The time at my disposal for the actual work was short, owing to the lengthy voyage: only two months remained for me to carry out the examination of the entire district, and to search for further outcrops of the beds, to describe, measure, and correlate the strata in the different exposures, to collect and extract fossils and to determine horizons, to make plans to scale of the chief outcrops and a map of the neighbourhood, as well as to take a series of illustrative photographs of the beds.

Contrary to expectation, there was no definite bone-bed: isolated bones only occurred at wide intervals, and nearly always in a fragmentary or shattered condition; hence it was practically useless to employ native labour.[2]

I am greatly indebted to Dr. C. W. Andrews and to Mr. R. B. Newton for their reports accompanying this paper on the Vertebrata and on the Mollusca respectively.

II. Description of the Miocene Series of the Victoria Nyanza.

Broadly speaking, the entire series of these lacustrine sediments may be classified into the following three groups, according to their dominant character; but there is no unconformity or discontinuity

[1] At the instance of Dr. A. Smith Woodward, F.R.S., the expenses of the journey were defrayed by subscription, chiefly by the generosity of Mr. Charles Storey, F.G.S., and also by the late Rev. R. Ashington Bullen, Sir Henry Howorth, F.R.S., Dr. G. B. Longstaff, Dr. A. Smith Woodward, Mr. W. Heward Bell, Mr. H. R. Knipe, the late Mr. W. H. Sutcliffe, and Mr. W. E. Balston; and I also received special facilities for railway-transport in British East Africa by kind permission of the Secretary of State for the Colonies.

[2] The district is malarious, and lies in the heart of an area devastated by sleeping-sickness. All reconnoitring has to be undertaken on foot, for no horse can live in this country of the tsetse-fly; the season happened to be phenomenally hot, even for this Equatorial district, the shade-temperature averaging 95° Fahr. and sometimes reaching 110° Fahr. Sir Percy Girouard, then Governor of British East Africa, kindly placed the little Government schooner at my disposal, thus enabling me to save time in reaching Karungu from the railhead at Kisumu. I have also great pleasure in acknowledging with gratitude the ready assistance and hospitality of Mr. C. W. Hobley, C.M.G., H.M. Provincial Commissioner at Nairobi, Mr. John Ainsworth, C.M.G., H.M. Provincial Commissioner at Kisumu, Mr. D. C. Crampton, H.M. District Commissioner at Kisii, and Dr. B. W. Cherrett at Kisii; and in tendering my thanks to Mr. Waller, H.M. Director of Government Transport, who rendered me much assistance on my arrival at Mombasa.

of sedimentation to be observed anywhere in the series, although changes in character are frequent:—

(1) An upper series (average thickness = 70 feet) of grey and brown clays and shales, containing very few fossils. Beds of sandstone are of rare occurrence.
(2) A middle series (average thickness = 30 feet) of variable red and grey clays, with white sandstones in the lower half.
(3) A lower series (average thickness = 55 feet) of buff-coloured sandstones and torrential gravels (containing the *Dinotherium* Zone), passing down (at Nira) into clays and marlstones.

Travertinous beds occur at intervals throughout the whole series.[1] The exposures are in gullies and cliffs at Nira, Kachuku, and Kikongo, to the east of Karungu (see Pl. XXVI, and § III on the Distribution of the Miocene Series, p. 135).

(1) The upper series (Beds 1 to 12) forms a natural division, consisting mainly of pale-grey, sometimes brownish-grey clays, which frequently alternate with thin seams of shale (often with dendritic manganese oxide). Chiefly in the upper part (for instance, Nos. 3, 5, & 8, but also No. 11 at South Nira) beds of grey, fine-grained, argillaceous sandstones occur, usually current-bedded—generally about 3 feet thick and exceptionally (No. 3 at East Kachuku) 10 feet thick (see Pl. XX). They are composed of quartz-grains, large plates of biotite, and augite-crystals.

Fossils are extremely rare in this upper series, and usually occur only in the sandstones; for instance, a few land-shells in No. 8 (*Tropidophora nyasana* E. A. Smith, *Limicolaria*, *Cerastus*), an *Ampullaria* and a crocodile's tooth in No. 5, and an indeterminable river-crab and some Crocodilian scutes in the clay of No. 12 at Nira. At the very top of the series, immediately below the capping of nepheline-basalt, the grey clay of No. 1 contains portions of calcified tree-trunks ranging up to 1 foot in diameter and 1½ foot in length, of Dicotyledons. They have been examined under the microscope by Miss N. Bancroft, who finds that the specimens represent types belonging to the Malvaceæ (similar to the African *Bombax insigne*), to the Geraniales (*Humiria*), to the Papilionales, and to the Caprifoliaceæ (similar to some species of *Lonicera* and *Viburnum*). Since one of these stems, in the same state of mineralization, occurred embedded in the lower brecciated portion of the basalt-flow at Kachuku, it seems probable that they had been fossilized by the agency of calcareous springs at the time of the deposition of the grey clays, and before the eruption of the basaltic lava-flows.

Thin beds of travertine alternating with grey clay are characteristic of the horizon of Nos. 9 & 10 in the eastern area, but do not occur at Nira in the extreme west.

Immediately below the sandstone of No. 8 at Kikongo, in the extreme east of the area, a breccia (1 foot thick) occurs of coarse

[1] The detailed measurements and descriptions are given in the comparative table of the outcrops exposed in the various gullies, Appendix I.

grey sandstone with angular and but slightly rolled fragments (measuring up to an inch and a half in diameter) of pink and grey gneiss, green andesite, and quartz, all derived from the country farther east, which seems to point to fairly-close proximity of the land. Here, too, at Kikongo, at the base of No. 12, another bed of sandstone occurs, which is not found farther east.

(2) The middle series (Beds 13 to 25) is much more varied in character, and fossils are more frequent. In general, the tendency of the clays to become red is very marked; thin beds of travertine occur at intervals, and sandstones and gravels prevail towards the base.

Transitional conditions are indicated by No. 13, which consists of about 5 feet of greenish-grey clay (sometimes speckled with flakes of biotite), with intercalary layers of pink concretions. Some fragmentary Chelonian remains (ribs and scutes of *Trionyx*) and a large Artiodactyl astragalus were the only fossils obtained at this horizon.

The most persistent bed in the whole of the Miocene Series is No. 14, which constitutes a marked physical feature, giving rise to a nearly level terrace, fairly wide at Nira and forming the upper edge of a small cliff. Typically this bed consists of a dull-red hard marlstone, passing occasionally either into impure travertine or more rarely into a soft clay. In places it is mottled red and grey; usually it is only 6 inches thick, but it may swell out to 18 inches, and is traversed by vertical joints filled with calcite and limonite. The upper surface of the terrace presents the appearance of an irregular pavement of bricks. At the extreme east (Kikongo) it has lost its redness, and has become dark grey. It is characterized by numerous casts of *Ampullaria ovata* and *Lanistes carinatus*, also opercula of the former, together with fragmentary Chelonian and Crocodilian remains. A similar bed yielding similar fossils occurs with less constancy in the upper part of No. 15, which consists of rapid alternations of red clay and thin layers of pinkish-white calcareous concretions, somewhat resembling lösspüppchen. Probably they were formed by gentle currents disturbing the deposits from calcareous springs in a muddy lagoon. The redness of the clay is inconstant, and frequently passes into a grey or greenish-grey. No. 15 thins out eastwards.

Nos. 13, 14, & 15 form essentially a natural group (10 to 12 feet thick) separated from a somewhat similar group (Nos. 18, 19, & 20, 8 to 12 feet in all), in which red clay predominates (with numerous inconstant seams, 1 to 2 inches thick, of argillaceous travertine), by a very constant horizon (1 to 2 feet thick) of Nos. 16 & 17. In No. 16 (see Pl. XXI), a grey argillaceous sandstone, I found a very few but interesting jaw-bones of a small new type of Hyracoid (*Miohyrax oswaldi*), with *Ampullaria ovata*, scutes of *Trionyx* and crocodile. No. 16 overlies a sandy clay (No. 17), the last-named bed enclosing an occasional seam of sandstone with similar Crocodilian and Chelonian remains, all in a very fragmentary condition. Fossil bones are a little more frequent in the lower part (Nos. 18

to 20) of the series, and coprolites (probably Crocodilian) are characteristic of these beds. No. 20 at Nira displays an interesting instance of a contemporaneous water-channel in the underlying clay, now filled up by a buff-coloured sandstone.

Nos. 21 to 23 form another natural group, consisting of pale-grey or even white sandstones, current-bedded, and sometimes exceedingly hard. Towards the east they become argillaceous, and even pass laterally into grey clays (at Kikongo), mottled sometimes with red. Where the sandstone becomes gravelly, the constituents are usually of grey sandstone (apparently derived from older beds in the Miocene Series), together with quartz, ironstone, green andesite, and pink gneiss. In the lower sandstone (No. 23) of Nira I noticed a number of stylolithic concretions, lying adjacent one to the other, each consisting of spiral coats, and probably due to some special conditions of contraction during consolidation. As soon as the beds become more arenaceous fossils occur more frequently, and in the hard sandstone (No. 22) of Kachuku I found the tibia of a Proboscidean somewhat resembling that of *Dinotherium*, associated with *Ampullaria* and a *Podocnemis*. Chelonian and Crocodilian remains occur in all the sandstones of this series, and I was able to restore a nearly complete carapace of *Cycloderma victoriæ* (from about a hundred pieces) occurring in the white sandstone of No. 21.

Nos. 24 & 25 form a natural group, composed of a fine orange gravel (No. 24) overlying a greenish-grey clay with seams of cellular travertine. The gravelly sand is only a few inches thick (3 to 9 inches), but constitutes a very definite horizon. It is of special interest for containing teeth, not only of Crocodile and *Dinotherium*, but also of *Protopterus* (which has not, I believe, been found hitherto in a fossil condition) and of rodents similar to *Phiomys*. The underlying greenish-grey clay of No. 24 contained opercula of *Ampullaria* and fairly numerous shells of *Cleopatra exarata*. The grey clay of No. 25 (sometimes reddish towards the west) contains remains of *Trionyx*, coprolites, and part of a tusk, probably of *Dinotherium*.

(3) The lower series (Nos. 26 to 37) includes beds of a more torrential character than the preceding.

Nos. 26 to 29 form a variable series (7 to 8 feet thick) of sandstones and gravels, becoming coarser and more calcareous towards the base; the constituents comprise not only grey sandstone, quartz, pink gneiss, and green andesite, but also jasper. At Kachuku No. 28 forms a coarse, nodular, calcareous conglomerate, and most of the pebbles have a calcareous coating; it often contains large lumps (measuring up to 2 feet in diameter) of yellow marlstone, evidently derived from a lower bed, enveloped in several concentric coatings of carbonate of lime. Fossils are very sparing and fragmentary in these gravels, and mainly consist of Chelonian and Crocodilian remains with coprolites and a fragment of *Dinotherium*-tusk. The beds of gravel are lenticular and inconstant,

and in the gully of South Nira Nos. 28 & 29 are altogether absent.

This group of gravels rests upon a remarkably persistent conglomerate (No. 30) of calcareous nodules (but not extending far to the east of Kachuku), passing in places into a nodular sandstone of such hardness that, where it has been undercut by the action of temporary waterfalls in the gullies, it only breaks off in large slabs measuring 12 by 4 feet or thereabouts (Pl. XXII, fig. 1). In some cases I found a nodule, with its many concentric coats, containing a fossil, such as a *Trionyx* scute, for a nucleus; but often no definite nucleus could be traced. The nodules have not been sorted according to size, but lie haphazard in a white calcareous cement, from small pebbles up to boulders 2 feet in diameter. They are always, however, ellipsoidal like river-pebbles and, when they are fractured, the fracture-planes prove to be frequently coated with dendritic manganese.

Below this conglomerate occurs a very variable group (No. 31) of grey or brown clay with *Ampullaria ovata* Olivier and *Cleopatra bulimoides* Olivier, brown seams of marlstone, and calcareous conglomerate at the western end (at Nira) of the outcrop; but towards the east, at Kachuku, this group (only exposed in a narrow gully) consists of 6 feet of grey clay overlying 14 feet of hard buff-coloured sandstones, current-bedded and having streaks of pebbles, very similar to the Triassic pebble-beds at Nottingham. They enclose two zones of gravel composed of overlapping lenticular beds (the pebbles consisting simply of quartz and ironstone), and it was only in these hard gravels that bones occurred, often much shattered and fragmentary, and at wide and uncertain intervals.

The upper gravel zone immediately underlies a discontinuous layer of yellow marlstone (Pl. XXII, fig. 2), and is particularly characterized by remains of *Dinotherium* and Anthracotheres (*Brachyodus*, *Merycopotamus*, *Merycops africanus*, etc.), Rhinoceros, a Carnivore (*Pseudælurus africanus*), part of the carapace of a giant Tortoise (*Testudo*), *Trionyx*, Crocodile, and a land-shell (*Cerastus mœllendorffi*).

In the lower gravel zone only much shattered Chelonian remains were present. Grey travertine, 2 feet thick, is visible at the base of this zone.

Nos. 32 to 36 form a variable group of brown clays, alternating with orange-brown marlstone (32 & 34) containing *Ampullaria* and *Cleopatra*, and often exhibiting small cavities lined with calcite-crystals. At West Kachuku this group passes into brown clay with layers of travertine, overlying a buff-coloured sandstone enclosing streaks of gravel and lenticles of travertine. This in turn overlies an orange-brown marlstone containing so much angular quartz that it becomes a quartz-ironstone breccia, facing the Kuja Plain in a low cliff at West Kachuku.

Finally, the lowest bed (No. 37) is a mottled dark-crimson and yellow clay (6 to 12 feet) overlying (at Nira) a dark-

green amphibolite[1] belonging to the basement-floor of schists and gneisses, upon which these Miocene beds were deposited. (See § IV, p. 138.)

Summary of Physical Conditions.

The quartz-ironstone breccia was probably derived from the weathered products of the old land-surface, which must have accumulated to a great thickness before the transgression of the lake formed the lagoon in which the Miocene Series was deposited. Therewas doubtless a more or less steady subsidence throughout the period of deposition, rapid at first and gradually diminishing in intensity. To these earth-movements may be ascribed the formation of the quartz-veins which traversed not only the basement of amphibolites, but even penetrated for a short distance into the lowest clays (at Nira), accompanied by ferruginous thermal waters reddening the basal clays. Calcareous springs were also active, especially in the lower section of the deposits, but travertine was formed intermittently up to the top of the whole series. The torrential character of the sediments brought down by a large river (probably the precursor of the present Kuja) is prevalent in the lower series, as shown by the frequent alternation of current-bedded sandstones with beds of gravel at Kachuku; but farther west, at Nira, the older part of the same period is represented by a prevalence of clays and marlstones, while on the east the whole series is missing. The upper part of the lower series is marked by the formation of beds of calcareous nodules, showing the existence of fairly strong currents, capable of rolling along and keeping in constant movement large and heavy nodules up to 2 feet in diameter in the lime-laden waters of the lagoon or shallow gulf. This was followed by a well-marked torrential period of calcareous gravels, the constituents of which were derived, not from the south, but from the east.

The middle series marks a transitional period when the new river-system was becoming mature, wherefore torrential deposits are exceptional and temporary, forming only thin beds of fine gravel. White or pale-grey current-bedded sandstones are characteristic of the commencement of this series, but there is a continually increasing tendency to deposit finer and yet finer sediments until red clays predominate, interrupted by travertinous layers and more rarely by thin seams of sandstone. The remarkable persistence of the travertinous marlstone of No. 14, which is readily recognizable from Nira to Kikongo (where, however, it has lost its redness and has become quite grey), seems to indicate the presence at this

[1] The rock is a fine-grained felt of green acicular hornblende, abundant microlites of an acid labradorite, quite fresh and doubtless secondary, and fine aggregates of small quartz-granules. A few unaltered grains of ilmenite still occur, although it has mostly been changed to leucoxene, and there is a little zoisite and diffused calcite. The original rock was, not improbably, a dolerite.

time of a calm lagoon, communicating with the main body of the lake to a sufficient extent to allow the molluscs *Ampullaria* and *Lanistes* to live in its waters and to be preserved in this bed. The remark may be made, in passing, that no bivalves were preserved in any of the deposits—a circumstance difficult to explain, in view of the abundance of *Unio*, *Ætheria*, *Sphærium*, etc., on the shores of the present lake, unless the sediments were laid down at such a distance from land that the only shells capable of being deposited were those of gastropods which floated until they became waterlogged and eventually sank. At the present day, gastropod shells are seen floating on the lake several miles away from the shore.

The red coloration of the clays is the most marked feature of the middle series, especially in the western area, and perhaps indicates the activity of ferruginous springs in this district.

Finally, the upper series indicates the time when the rivers had nearly reached their base-levels, and were no longer able to bring down heavy loads: the sediments consist essentially of grey or brown clays alternating with shales, and interrupted quite exceptionally by grey sandstones, or more frequently by thin seams of travertine. These sandstones with large plates of biotite and augite-crystals probably were the product of unusually wet seasons, when the rivers were swollen beyond their ordinary dimensions. In the uppermost beds the petrified stems represent some unwonted circumstances, in which waterlogged tree-trunks were calcified by the agency of calcareous springs.

The upper series (averaging 70 feet) is nearly equal in thickness to the middle and lower series taken together. This circumstance, in conjunction with the argillaceous nature of the sediments, indicates that a very long period of time elapsed during their deposition; therefore, although the lowest beds are of Lower Miocene age, it is not impossible that the uppermost beds may extend even into the Pliocene.

III. Distribution of the Miocene Series.

These Miocene deposits have been almost completely overwhelmed by flows of nepheline-basalt, which do not, however, seem to have appreciably baked the underlying clays for more than a few inches; but the junction was everywhere obscured by thick downwash and overgrowth half way up the cliffs of East Kachuku and Kikongo. The insignificant amount of baking was probably due to the fact that the lava-streams had reached their southernmost limit, and had therefore already cooled down considerably.

The Miocene deposits are present along the southern margin of the lava-plateau, from Nira on the lake to Kikongo, $4\frac{1}{2}$ miles away to the east (Pl. XXVI, fig. 1), but unfortunately they are still for the greater part concealed beneath a thick covering of superficial deposit termed regur or black cotton-soil; and it is only in the gullies of Nira, Kachuku, and Kikongo that a relatively small

portion has been uncovered. The occurrence of stone-implements of a Neolithic character (chiefly made of devitrified obsidian, but also of quartzite and quartz-porphyry, all with a thick brown patina), which I found lying on the wide terraces of Beds 23 & 26, both at Nira and at Kachuku, seems to indicate that a considerable space of time has elapsed since the first formation of these gullies. Every year will see a larger area exposed by the torrents of the rainy season, and a periodical search by a geologist or by a Government official on his round of the province through Karungu would certainly result in important finds.

Everywhere I found the dip of these beds constant: namely, 8° north by west. As a result of this northerly dip, they soon disappear completely beneath the basalt-plateau, which extends for 30 miles northwards; and even the deep meridional valleys at Kitama and Kikongo failed to reveal any trace of them. These broad valleys seem to have been excavated in the deposits prior to the eruptions of the basalt, which flowed down into the valleys from the higher ground, completely covering and sealing up the lateral slopes. Another reason for believing that a great part of these deposits must have been destroyed by denudation before the outflow of the lava-streams, is founded on the circumstance that the continuity of the beds between Nira and Kachuku has been interrupted by a basalt-flow extending from Nira Hill down to the actual level of the plain, filling up an old valley which had been eroded in the soft clays and sandstones.

Even on the south, no traces of the beds could be discovered. In this direction the uplifted strata, which also thin out southwards, would have occurred at a continuously higher level, and were therefore more liable to be destroyed by denudation when the lake stood much higher than at present, or by the erosion of the Kuja and its tributaries.

South of the wide Kuja Valley I could find no indication of them in the hills of granitic gneiss, which extend to the Anglo-German frontier—despite the fact that this area is probably a depressed block of land, judging from the obviously drowned valleys lying between the long narrow promontories of Mohuru; but the initial formation of these valleys may have preceded the deposition of the Miocene sediments.

The shallowness of the Bay of Karungu, in sharp contrast with the steep gradients of the lake-bottom along the coast to the north and south, indicates that the Miocene deposits had once a considerable westward extension over the site of the bay, and have been destroyed by the action of the waves, which break on this shore in heavy rollers.

There are, indeed, indications that the series thins out southwards, and probably it never extended very far in that direction. The exposures, both at East Kachuku and at Kikongo, lie considerably (namely, 6 furlongs and 10 furlongs respectively) to the south of the line of strike of the outcrops at Nira and Kachuku, and in both the two first-named localities the lower beds have thinned out

considerably: for instance, Beds 30 to 36 are completely absent and only a trace of the crimson clay of No. 37 is visible at East Kachuku. Moreover, the lower beds of the middle series are already thinner, and the unproductive upper series of grey clays and shales is alone well developed in these two southernmost occurrences.

The only chance, therefore, of finding further outcrops was to search along the line of strike. After leaving Kikongo, I noted that the basalt no longer rested on the Miocene deposits, but directly upon an ancient and much-altered augite-andesite, which extends over a wide area, now completely deserted and given back to wild animals, owing to sleeping-sickness. Finally, I found what appeared to be an isolated remnant of the upper beds near Minyere on the Kuja River, 15 miles in a straight line from the lake-shore, tilted up at exactly the same inclination: namely, 8° north by west, at 3906 feet, very nearly the same altitude as Kachuku (3960 feet).

Here, in a gap on the wooded banks of the river, where lions and antelopes come down to drink, I found the following downward succession, similar to No. 3 of Nira or No. 4 of Kikongo:—

	Thickness in feet	*inches.*
(1) Hard brown shale	0	6 to 9
(2) Brown clay	1	0
(3) Brown shale	0	6
(4) Brown clay, becoming sandy in the lower part, and overlying the old augite-andesite, which extends in rocky masses of angular boulders more than halfway across the river	8	0

In another exposure, 100 yards farther down the river, grey clays were visible, forming a low cliff in a broad tributary valley, about 50 yards away from the Ogo Ford of the Kuja; they probably belong to a lower horizon, and are similar to No. 9 of Nira and Kachuku:—

	Thickness in inches.
(1) Hard grey clay, shaly in the lower 3 inches	9
(2) Grey shale	3
(3) Grey clay	3
(4) Limonitic clay	9
(5) Grey clay, base not seen	12

The broad valleys in this region, tributary to the Kuja, all show a grey clayey soil, perhaps due to washed-out remnants of these deposits.

Although not a trace of fossils was visible, it was clear that the character of these beds is altogether different from the homogeneous river-alluvium of the opposite bank. They are precisely similar to the upper beds of the Miocene Series as seen at Nira, East Kachuku, and Kikongo; they occur on the same line of strike and at the same altitude, and show the same dip. Hence, it seems only reasonable to consider that this occurrence represents the easternmost remnant of the beds, and that they have been completely denuded away from any part of the intervening andesitic

area which they may once have covered. Probably this extensive denudation was not so much subaërial, as due to the lake having stood for a long period at a level of nearly 4100 feet above the sea: that is, about 328 feet above the present level, as indicated by the evidence which I adduce later (p. 146).

IV. Basement-Floor of the Miocene Series.

The amphibolite at Nira is traversed by a vein of quartz a foot thick (running in a west-north-west to east-south-east direction), which passes up into the overlying crimson clay, and extends also laterally. It is evidently owing to associated ferruginous solutions that both the amphibolite and the originally yellow clay are traversed by a network of veins with dark crimson staining. In the gully of South Nira the amphibolite passes upwards into about 20 feet of rotten rock (a grey, sandy, brown-veined clay), covered by a foot of brown ferruginous sandstone, probably representing the ancient ironstone soil or murram which cloaked the older rocks prior to the transgression of the lake in Miocene times. This basement-floor of amphibolite is not level, but rises in small irregular bosses and ridges, with a north-westerly strike, covered by the crimson basement-clay (No. 37); on the south-eastern and eastern side of the South Nira Gully it rises in a rounded knoll, which is directly overlain and flooded by the nepheline-basalt from Nira Hill.

This basement is not actually visible at Kachuku, but the cliff of quartz-ironstone breccia at West Kachuku is probably the old soil of the amphibolite, somewhat remanié by the transgressive waters of the lake, and it is overlapped by the crimson clay (No. 37). It forms a low bare ridge with north-westerly strike, stretching towards Nira, and it is free from the envelope of black cotton-soil extending on each side. Farther east the crimson clay, cropping out about 150 yards from the base of the cliff of East Kachuku, overlies a similar quartz-ironstone breccia, full of particles of angular quartz (up to 2 inches in longest diameter) and of partly rounded ironstone. Lower down the slope a pale greenish-grey phyllite [1] crops out from under this ironstone breccia, having a foliation directed 30° south-south-west and a north-north-west to south-south-east strike. It forms the western and southern selvage to the rounded hill of Rabur, and borders the alluvial plain of the Kuja. Rabur rises rather abruptly out of the gentle slope of the schistose area, and consists of a dark-green fine-grained zoisite-hornblende rock.[2] It is probably an altered dolerite, and weathers into rounded blocks, contrasting with the splintery chloritic calc-

[1] It consists essentially of calcite and chlorite, with abundant leucoxene in drawn-out lenticles and a little quartz.

[2] The rock is chiefly composed of green hornblende in sheaves of bladed crystals, together with zoisite and some quartz in very fine aggregates. Ilmenite is rather abundant, often altered marginally to leucoxene; pyrite and epidote are accessory.

schist at its base. It is noteworthy that the amphibolite of Nira occurs exactly on the prolonged line of strike of the schist. This chloritic schist perhaps represents the strongly-sheared selvage of a zone of amphibolites lying north of the broad zone of gneiss that occurs on the south of the Kuja Plain (see p. 140).

At Kikongo, the junction of the Miocene beds with its basement-floor is greatly obscured by downwash and murram; but, on the eastern side (in the Kitama Valley), a boss about 100 yards in diameter of the underlying igneous basement crops up. The rock is a highly-altered and decomposed hornblende-porphyrite with massive jointing, and probably represents an ancient intrusive mass; the microscope reveals no evidence of any pressure-metamorphism. In this case, and in several others, it was impossible to obtain fresh and unaltered rock-specimens, owing to the great depth to which alteration has taken place.

South of Kikongo the lower slopes immediately below the deposits consist only of quartz-ironstone breccia, and the underlying rock was not revealed until I reached a point 2 miles away to the south, where a very much weathered and chloritized amphibolite rises out of its thick mantle of ironstone-breccia. It is not unlike a much-altered and coarser variety of the amphibolite of Nira. The rock is but slightly schistose (dipping 67° south-westwards), and shows the north-westerly and south-easterly strike which is characteristic of the metamorphic area east of the Victoria Nyanza. It has weathered deeply to a rich orange-brown soil with some quartz, exactly in the manner of the other amphibolites.

The next hill on the east, separated by a broad shallow valley, only shows the usual quartz-ironstone breccia, but it is traversed by a reef (striking north-east and south-west) of brownish quartz, 10 feet thick, veined with white quartz. The neighbouring hills on the east and south-east are similar in appearance and composition.

South of Nira and Kachuku the wide alluvial plain of the Kuja Valley extends for 5 miles, unbroken in relief excepting for nests of termites, 10 to 15 feet high. Towards the lake-shore the brown sandy soil occurs in gentle ridges, probably marking old storm-ridges. Very often the soil is black between the ridges, with occasional angular pieces of basalt derived from the regur which occurs near the shore between Nira and Karungu. The Miocene deposits probably extended originally for a considerable distance southwards over the site of this alluvial plain. The Kuja flows now along the southern border of the plain; in the dry season its banks rise about 20 feet above the river-level, and consist of homogeneous brown alluvium without any shells. In one place (below the last ford), a layer of black alluvium (derived from regur from the north) is intercalated midway in the brown river-mud; but there is no sign of shaly lamination.

Almost immediately south of the river is a wide zone of grey gneiss of granitic appearance. The outlying hills, such as Nakanero (altitude, 4040 feet) and Angaohi (4006 feet), rise out of river-alluvium to a height of about 300 feet above it, and were obviously

once islands when the lake stood at a higher level. Still farther south the bays of Gurekeri and Mohuru are just as obviously drowned valleys, and this characteristic becomes increasingly pronounced in the gulfs farther southwards as far as Mwanza. But the lake at the present day is falling in level, and therefore these drowned valleys are no longer so deeply submerged as they once were.

This gneiss[1] weathers into large bare blocks, usually rounded, but sometimes angular, often longer than broad, and vividly recalling the granite-tors of Devon and Cornwall. Both in this and in the other instances of granitic gneiss which I observed in the Nyanza province, the gneiss is so much fresher than the schists, that it is probable that they are of later date, as in Rhodesia, and that they have undergone only a slight amount of pressure. Most of the occurrences present the appearance of having originally been intrusive granites.

V. The Basalt-Plateau of Gwasi.

The Miocene beds are capped by the terminal lava-flows belonging to the basaltic system of Gwasi (6384 feet), the central peak of which rises 17 miles north of the southern tongues of the lava-streams that have buried up the sediments. On sailing round this massif of Gwasi, from the Kavirondo Gulf to Karungu, I was struck by the resemblance of the scenery to that of the basalt-plateau of Skye and the Western Highlands, the lofty cliffs consisting of flow upon flow of columnar black basalt like Ben More in Mull; while the flat-topped outliers, now detached by extensive denudation, are the exact counterparts of Macleod's Tables in Skye. The outlying islands of Mfwanganu on the north-west and of the symmetrical pyramid of Nagodaluru on the south-west once (as shown by the soundings) stood in connexion with the main mass. The neighbouring systems of Gembe (6208 feet) on the north, of Ruri (5583 feet) with its many cones on the north-east, and even of Homa (5742 feet) still farther north-east, consist of the same nepheline-basalt or nephelinite, and form a geological unity.

Although the basalt, at a superficial glance, appears to be of very

[1] The felspar and quartz prevail over the ferromagnesian constituents; the orthoclase allotriomorphs (up to 5 mm. in length) are often turbid centrally with decomposition-products, and enclose an occasional granule of kyanite and zircon—the cleared margin often shows undulose extinction, with patches of fresh microcline developing at its expense. Plagioclase (oligoclase-andesine, Ab_5An_3) is quite subordinate. Quartz occurs in granulitic mosaics, with rough parallelism bordering the orthoclase-crystals, and here sometimes shows a myrmekitic intergrowth. Green hornblende is present in larger crystals (up to 4 mm. in length) than the biotite with which it is associated, but is not so frequent, and shows the usual pleochroism (α, pale straw; β, sap-green; γ, blue-green). Biotite occurs in greenish flakes, enclosing apatite and small zircons with pleochroic halves. Sphene is accessory in pale-brown, rather large crystals, sometimes bordering the rare grains of magnetite; and a few granules of pyrite are present.

uniform texture and composition, it is, on the contrary, extremely variable, exactly like other nepheline-lavas. The most typical variety is a specimen[1] which I collected south of Homa Bay, on the Rungwena Plateau, belonging to the Ruri system. It presents many points of similarity to the nepheline-basalt of Fogo in the Cape Verde Islands.

The regularity of the slope from the central mass, right down to the last lava-streams at Nira and Kikongo is very distinct, when viewed from the lake or from the Kuja Plain. In several cases, it is clear that many of the now isolated hills that rise above the Bay of Karungu have been carved out of the plateau by denudation, whether they are flat-topped hills such as Omangi (4532 feet) or conical peaks such as Tigra (5031 feet) and Okai (4857 feet), which still show a lava-flow in section capping their actual summits. The lava[2] on Nira Hill, for instance, was clearly once in continuity, not with Nundowat on the east, but with flat-topped Omangi on the north-north-east, but it is now separated by a wide and deep valley. On the other hand, it is also evident that there were several subsidiary points of eruption, even so far south as the peak of Nundowat (4479 feet), almost at the southern limit of the plateau, overlooking the Miocene deposits. It is a boss of huge

[1] The black compact rock, with irregular fracture, contains numerous crystals of pale-green augite (diopside) measuring up to 11 mm. in longest diameter, with frequent twinning, both simple, lamellar, and herring-bone, often zoned, and sometimes bordered by augite of a darker green; occasionally enclosing magnetite-grains, a nepheline-crystal, or some brown glass full of microlites. A few rather small crystals of olivine have been serpentinized and stained yellow by iron oxide, and in several cases are surrounded by a wreath of green augite and magnetite-granules. Nepheline is present in large fresh idiomorphs, enclosing augite-needles and magnetite, as well as in small quadratic crystals. Magnetite is abundant in large hexagonal crystals, down to quite small dimensions. Apatite is fairly frequent, enclosing numerous minute, purple-black, longitudinal rods. The ground-mass consists of a close felt of augite- and magnetite-granules, with occasional clear streaks of allotriomorphic nepheline, into which larger needles of green augite project.

[2] This rock is very similar to the Rungwena basalt, and contains similar augites but no porphyritic nepheline; and, since no olivine is present, it would be properly termed a nephelinite rather than a nepheline-basalt. On the other hand, it contains some pale-brown, nearly resorbed hornblende-crystals, sometimes surrounded by a wreath of augites with occasional small flakes of biotite. In the clear streaks of allotriomorphic nepheline in the ground-mass occur some instances where allotriomorphic sanidine seems also to be present; but the twinning is much less sharp than usual.

C. Uhlig collected some specimens of the lava 1600 yards inland from Karungu, and here, according to the description by M. Goldschlag ('Beiträge zur Kenntnis der Geologie & Petrographie Ostafrikas I.' Centralblatt f. Min. 1912, pp. 567 & 593), it proved to be nephelinite, since no olivine was present; it contained allotriomorphic nepheline, like my specimens collected a little farther south. Uhlig's three specimens were taken all close one to the other, but showed considerable variety: in one case nepheline occurs mostly in the ground-mass, and is only occasionally idiomorphic; the proportion of nepheline-crystals increases in the second specimen; and, in the third specimen, the nepheline is almost exclusively in the form of idiomorphs, while the ground-mass contains some glass in this specimen alone.

angular boulders of scoriaceous nepheline-basalt[1] (see Pl. XXI), 30 yards in length from south-west to north-east and 20 yards wide, rising rather abruptly to a height of 30 or 40 feet from the general surface of the lava-plateau.

The lava on the surface of this plateau is highly scoriaceous, with steam-cavities measuring up to 4 inches in length, and it descends very steeply, but apparently with its original slope, into the valleys of Kachuku on the south and of Ubware on the north. In both these cases I found the lava-stream to be highly brecciated with large fragments of its own substance, indicating its superficial character; and, near the head of the Kachuku Valley, I noticed that the lava-stream had not merely caught up and rolled along cooled fragments of its own substance, but contained one of the calcified tree-stems from the uppermost clays of the Miocene beds over which the lava had flowed.

The nepheline-basalt seems to be particularly susceptible to atmospheric denudation, and, owing to its homogeneous nature, it weathers readily into conical hills. The outlier of Homa still preserves the plateau-like character, although the detached northern peak is conical. The dissection of Ruri is much farther advanced, and it consists entirely of a group of cones, while the outliers on the extreme eastern margin of the basaltic area consist of separate symmetrical cones: for instance, Chamanga, Uchimbo, and Asego, rising with remarkable abruptness (slopes of 32°) from the level alluvial plain.

The products of denudation of the nepheline-basalt consist of black cotton-soil or regur, a black alkaline clay (very sticky and plastic when wet, but friable and cracking readily when dry). Everywhere in this area the regur swathes the lower slopes of the basalt hills in a thick mantle, and fills up the valleys. As Mr. H. B. Maufe has remarked,[2] the most suitable conditions for its formation are to be found on

'level or gently rolling ground where the rocky substratum is impervious and the under-drainage consequently bad.'

Now, the clays of the Miocene beds form a completely impervious substratum, and here I found the greatest thickness of regur: namely, up to 20 feet. Everywhere it contained land-shells (*Tropidophora* sp.) still showing colour-bands, with occasional angular fragments of basalt; and in the lower half the little grey, rough,

[1] This rock is also very similar to the Rungwena basalt, but contains no porphyritic nepheline; the augite shows the same characteristics, and serpentinized olivines are also present, with a very few flakes of biotite, in a somewhat similar ground-mass of looser texture. The nepheline of the ground-mass has, however, become more individualized, although not showing crystal-outlines; allotriomorphic nepheline enclosing small augites and magnetites forms the major part of the matrix; the remainder consists of a yellowish base, probably serpentinized glass. A single hexagonal crystal of leucite is visible in the slide.

[2] 'Report relating to the Geology of the East Africa Protectorate' Colonial Reports, Miscellaneous, No. 45, 1908, p. 55.

calcareous concretions or kunkar are frequent, while in the wide valley of Wawengi (between Karungu and Omangi) bones of antelope, zebra, warthog, etc., sometimes occur: probably the animals were mired in the extremely sticky black clay during the rainy season.

The presence of this regur with land-shells over the zone of Miocene beds along the foot of the lava-streams, and the absence of any freshwater shells, would seem to indicate that this area has not been submerged by the lake since the uptilted Miocene deposits were concealed by lava. In the gully of West Kachuku, however, the lower half of the regur showed a roughly-stratified layer of boulders of basalt with fragments of the Miocene sandstones, and these were probably brought down by a temporary torrent during an exceptionally heavy rainfall.

Inland the impervious substratum necessary for the formation of the regur is provided by a yellow loam; for instance, in the Kitama Valley, 4 feet of regur overlay 6 feet of yellow-brown loam (derived from the disintegration of the basalt), containing small lumps of kunkar and land-shells, together with occasional angular fragments of basalt (about 2 inches in diameter), and weathering in vertical walls, the whole presenting great similarity in appearance to the lœss of China. Similar relations between the regur and the lœss occur also in the wide valleys draining into Karungu Bay.

It was exclusively in the basaltic region that I observed this black earth, both in the Karungu district and again over the Rungwena Plateau (south of Homa Bay) nearly as far as Langueh. In the banks of the Agulu Muk River, which cuts through this plateau, I noticed the following succession:—

	Thickness in feet.
(1) Regur	4
(2) Compact, calcareous, brownish-grey loam (lœss), with fragments of basalt	3
(3) Soft grey clay, with fragments of basalt	4
(4) Coarse yellow gravel, with partly rounded blocks (measuring as much as 18 inches in longest diameter) of quartz-porphyry, quartzite, andesites, and banded jasper, dipping 5° north-eastwards, that is, towards the river	3
(5) Quartz-porphyry *in situ*, much decomposed.	

As one descends to the lake from the Rungwena Plateau, the following section is seen in the right bank of the Rungwena River:—

	Thickness in feet.
(1) Regur	3
(2) Hard grey volcanic tuff, dipping 8° north-north-westwards, that is, towards the river	1
(3) Brown clay, with sparse pebbles of quartzite, granite, basalt, jasper, and ironstone	4

Nearer still to Homa Bay, Seminya and the hill west of it consist of a grey volcanic tuff, dipping 2° northwards, veined with hæmatite. Probably Ruri was the centre of the explosive action which gave rise to these tuffs.

VI. Geology of the Country between the Victoria Nyanza and the Kisii Highlands.

The gneisses and amphibolites forming the foundation upon which the Miocene beds repose, together with the nepheline-basalts which cap them, have already been described, and a reference has been made to the old augite-andesite that occurs east of Kikongo. This augite-andesite,[1] together with its agglomerate, has a considerable distribution, extending for 11 miles from near Kikongo eastwards to Gongogongo, and from Nonnia south-eastwards for at any rate 9 miles and probably much farther. The hills and ridges of this andesite have the same north-westerly and south-easterly strike as the rest of the gneissic area, yet there is no evidence of cataclastic structure in the rock, although it has been much altered (the augite, in particular, being uralitized), and it is everywhere traversed by thin veins of quartz.

The steep-sided hills of the andesite often display rugged crags and precipices, especially above the Gogo Falls on the Kuja River, in the Kodondo Cliffs, and in the striking hill of Nyakuru (4673 feet) with its twin peaks. This area has evidently undergone a great amount of denudation, whence we may infer that the rock now exposed was probably rather deep-seated originally.

An interesting circumstance is the occurrence at Metamala of the andesitic agglomerate weathering into picturesque rugged crags of bare rock, crowded with rounded masses (2 feet or more in diameter) of grey quartz-augite diorite,[2] and also of microgranite, gneiss,

[1] The rock is least altered at Kodondo (5 miles east of Kikongo). Here it is compact and greenish grey, displaying splintery fracture, crowded with tabular idiomorphs (measuring up to 4 mm.), dusty and saussuritized, of plagioclase (andesine, Ab_3An_2), and abundant idiomorphs (up to 3 mm.) of pale-green augite (diopside), much uralitized, the uralite in turn altering to chlorite and epidote. The augite is sometimes twinned, and contains apatite; when adjacent to a quartz-vein it is margined by a secondary brownish-green hornblende. Biotite is represented by a few pseudomorphs of chlorite with magnetite and a little epidote; originally it was partly resorbed. Magnetite occurs in large grains enclosing apatite, as well as small plagioclases and augites. Apatite and pyrite are accessory. The ground-mass is micropœcilitic, the texture being coarser round the bigger augites. Thin irregular veins of quartz traverse the rock.

At Nyakuru (3 miles south-east of Kodondo) the rock is nearly identical; but the augite has here been entirely uralitized, and the uralite has also been partly altered to chlorite; some original biotite, however, still remains unaltered, with a resorption-border of magnetite and actinolite.

At the Ogo Ford on the Kuja River (6 miles east-north-east of Kodondo) the rock is also very similar, but has undergone alteration to a greater degree, the uralitized augite having been replaced by chlorite, or by epidote and calcite, or even entirely by calcite. Yet the plagioclase is fresher than in the previous two specimens.

[2] In this rock plagioclase (oligoclase-andesine, Ab_5An_3) predominates in tabular crystals (measuring up to 1 cm. in longest diameter), with a strong tendency to idiomorphism: it is occasionally intergrown with orthoclase—zoning is seldom visible, and is confined to the margin, which is often composed of fresher felspar; it is sometimes partly intergrown with quartz peripherally, and contains chlorite along cracks, but is not so decomposed as

jasper, and andesite in a dark-green fine-grained matrix, so as to present the appearance of a puddingstone. The contained rocks do not, however, weather unequally, as might be expected, but in perfect uniformity with the matrix—as if the rock had been cut through sharply and cleanly with a knife, irrespective of its varied contents. Microscopic examination suggests that the diorite is merely the deep-seated form of the augite-andesite, the augite in both cases being uralitized; and the uniformity of weathering is further accounted for by the intimate manner in which both the matrix and the contained rock-fragments are penetrated by a network of thin veins of quartz.

Crags of this agglomerate occur on both sides of the Ogo Valley and up the Dodo Valley to Dodo and Taygoreh, as well as south of Metamala. On the periphery of the agglomerates, for instance, at Moroya, more than 5 miles south-west of Metamala, a dark-green banded tuff occurs (see footnote), very hard and compact, also silicified, but without the big rounded fragments; and this banded tuff also builds up the hills of Godateli and Yangena west of Metamala. The summit of Godateli is traversed by a thick vein of white quartz striking north-north-east and south-south-west, which has so resisted weathering as to cause the formation of this rounded hill above the rolling plain of tuff. The low hill between the Metamala and Moroya plains (covered by quartz-ironstone breccia) similarly owes its formation to the presence of quartz-veins and their resistance to weathering. Although time did not allow me to determine the limits of the agglomerate and tuff on the south-east, it is clear that they cover an area exceeding 5 miles in diameter, and mark the centre of eruption of the augite-andesites, which probably extend as far south-eastwards beyond the agglomerate as they do westwards and north-westwards.

The agglomerate and tuff weather to a mixture of ironstone and quartz, and honeycombed patches of murram are frequent here, as on other ferruginous soils.

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the orthoclase, which is subordinate in amount and turbid. Green hornblende is abundant in imperfect crystals (up to 3 mm.) with a uralitic aspect, the uralite changing to chlorite, calcite, and epidote. Some biotite (associated with the hornblende) was originally present, enclosing apatite, but is now altered to epidote and calcite. Sphene and magnetite are accessory. Quartz is abundant in interstitial granules, sometimes with strings of fluid inclusions. Fine veins traverse the slide, filled with quartz and epidote, or else recemented by secondary minerals—a fractured quartz-grain by secondary quartz, felspar by felspar, and hornblende by hornblende.

In the tuff of Moroya, on the southern periphery of this outcrop of agglomerate, the fragments consist essentially of the constituents of the diorite, but with diopside only partly uralitized, the uralite changing into chlorite (exactly as in the andesite of Kodondo). Hence the hornblende of the diorite is probably all derived from augite, and the original rock would have been a quartz-augite-diorite.

The tuff, both at Metamala and at Moroya, is a crystal-tuff composed of the constituents of the diorite, and numerous fragments of microlitic felts of quartz with oligoclase-microlites ; both rocks are traversed by fine veins of quartz (sometimes with epidote), and are evidently very siliceous.

Along a zone about 50 feet above the present level of the Kuja Valley (that is, at an altitude of about 4000 feet), occur quantities of well-rounded pebbles of quartzite (measuring up to 6 inches in length), which have evidently been brought down by the Kuja from the parent-rock of the quartzite of the Kisii Highlands at a time when the river flowed at a higher level than at the present day. This zone of quartzite-pebbles is well marked along both sides of the Olasi Valley, especially on its south side, between Nangina and Nyaroya, and also along the low ridge above the Ogo Ford north of Yangena.

Although further evidence is necessary, it seems to me probable that this zone of pebbles at the 4000-foot level marks an old beach-line of the Victoria Nyanza. It is extremely noticeable, both in this district and in the area south of the basaltic cliffs of Nira, Kachuku, and Kikongo, that all the hills and contours below this altitude are gentle and rounded (for instance, Rabur), with particularly broad valleys; while abruptly above this level I noticed pointed hills (for instance, Mirema), terminating in rough and rugged crags. Exactly the same striking contrast is noticeable in looking across the Kavirondo Gulf from Kendu, vividly recalling the contrast in Norway between the lower rounded glaciated slopes and the non-glaciated crags and peaks above them. This level is roughly about 300 feet above the present level of the lake, which must (at this altitude of 4000 feet) have just reached to the foot of the basaltic cliffs, and must have chiefly contributed to the destruction of the Miocene deposits at their base. On the western shore of the Victoria Nyanza, gravel-deposits and caves occur at a height exceeding 300 feet above the lake in the cliffs of the coast of Buddu, north of the Kagera River.[1]

In proceeding eastwards from Metamala I found that the coarse agglomerate persists up to the gneiss of Gongogongo, without passing into tuff as it does on the west and south. The acacia forest on the steep slopes of this range of hills precluded any exact observations of the mutual relations of these rocks, but the gneiss forms a gigantic obelisk of colossal, bare, rounded blocks, thus constituting a natural landmark for many miles round. The rock is a pink granitic biotite-gneiss,[2] weathering pale brown, and probably was originally an intrusive granite. On the north-east side

[1] Sir William Garstin, 'Report on the Upper Nile' Cairo, 1904, pp. 32–39.

[2] This rock contains numerous allotriomorphs (measuring up to 9 mm. in longest diameter) of orthoclase (microperthite), of tabular habit with Carlsbad twins, and traversed by a finely dusty perthitic network; sometimes displaying a brecciated margin of plagioclase. Plagioclase (oligoclase-andesine, Ab_2An_1) is subordinate, occurring in smaller crystals (measuring up to 7 mm. in longest diameter), often interstitial between the larger orthoclase-crystals; occasionally turbid centrally with flakelets of white mica, but clear marginally. Biotite (up to 2 mm.) is only sparingly present, sometimes with bent lamellæ; it encloses zircons with pleochroic halos, as well as magnetite and apatite. Magnetite is accessory, enclosing apatite. Quartz occurs in large interstitial grains, containing strings of very small fluid inclusions, and sometimes displays brecciated margins; it encloses biotite, and occasionally plagioclase.

of the Gongogongo Range a broad zone of amphibolite[1] extends for 5 miles through the district of Sakwa down to the Kuja River. Exposures are extremely rare, for the rock is greatly altered, and weathers to a considerable thickness of red-brown clay. Wide valleys opening out to the north-west alternate with steep grassy ridges.

North of the Kuja extends for many miles the wide plateau of Kamagambo, composed of a granitic hornblende-gneiss.[2] Its essentially level surface, and the fact that the Kuja has carved deep meanders into it, coupled with the presence of old river-gravels containing big quartzite-pebbles derived from the Kisii Highlands, serve to indicate that this plateau is essentially an old peneplain in which the Kuja has cut down its meanders to 300 feet below its surface, owing to the rejuvenation of its course, to which further reference will be made later on. The formation of the peneplain must have taken place at the time when the lake stood at the 4000-foot level, but slightly below the level of this gneiss plateau.

I left the district of Sakwa, and entered that of Kamagambo by a wooden bridge which has been constructed by native labour, replacing a ford immediately above some picturesque waterfalls at 4347 feet. Rapids are characteristic for several miles downwards from this part of the river's course. The gneiss weathers readily and deeply into pale yellow-brown or orange sands, or else into greenish-white clays; and the contrast is striking, between the gentle slope of the gneiss on the right bank and the steeper inclination of the more resistant amphibolite on the left.

Before one reaches the top of the grassy gneiss plateau a black peaty soil is noticeable in several places; but, on the actual summit

[1] The rock near the junction with the biotite-gneiss is a green, extremely close-grained zoisite-amphibolite, consisting of a very fine aggregate of granular zoisite, clinozoisite, and abundant bladed green hornblende in a quartzose matrix, with a few granules of magnetite. Some indistinct pseudomorphs after primary hornblende consist of secondary hornblende and zoisite, with magnetite-granules and some chlorite enclosing calcite. Clearer areas, consisting of aggregates of quartz, zoisite, and flakelets of white mica, may possibly represent original felspars. Chlorite enclosing calcite in lamellæ is probably after biotite. Calcite is diffused through the slide, and a little epidote is present. The original rock may have been a not very basic, rather finely crystalline basalt.

[2] A gneissose banding is suggested by successive wavy zones of quartz alternating with felspar, and by the hornblendes lying with their long axes parallel to these zones. Orthoclase predominates in allotriomorphic crystals (measuring up to 5 mm. in longest diameter), turbid with dusty decomposition-products and flakelets of white mica; it is altered in patches to clear albite, especially marginally, where it is sometimes brecciated. Green hornblende (measuring up to 2 mm. in longest diameter) is both primary and secondary; the primary is pale green, somewhat bent, containing apatite and magnetite, and alters along the cleavages into a yellow serpentinous mineral with some epidote. The secondary hornblende occurs only in association with quartz: it is fresh and unaltered, and sometimes twinned (α, pale straw; β, sap-green; γ, blue-green). Quartz is abundant as a fine granulitic mosaic, showing undulose extinction. Leucoxene is present in rather big dusky grains, with their long axes parallel to the planes of schistosity. Magnetite is accessory in crushed and drawn-out grains.

(4614 feet), a yellow-brown sand prevails, with frequent stretches of old river-gravel containing large quartzite pebbles, and patches of murram often occur in which these pebbles are sometimes embedded.

The plateau stretches far to the northward, but is dominated on the east by the lofty quartzite-escarpment, trending north-north-west and south-south-east, of the Kisii Highlands. This cliff rises 1500 feet above the level of the old peneplain, and stretches far away to the south-south-east; while on the north-north-west it ends in the bastion of Itumbe, still 6000 feet above the sea. The upper edge is precipitous, but the lower slopes show here an inclination of only 35°. The low rounded foothills at the base of the white quartzite-cliff are composed of a dark-green, very fine-grained dolerite,[1] forming a sill which has insinuated itself between the gneissic basement and the cover of quartzitic sandstones, changing the latter near the contact into snow-white quartzite—a conspicuous zone of colour in the face of the escarpment. The underlying dolerite weathers deeply to a thick red clay, which is very fertile, and hence determines the situation of the numerous settlements of the Kisii people. It forms the belt of lower ground, not only at the base of this Vinyo escarpment, but also within the deep gorge of the Kuja River, which has cut its way through the quartzite-plateau. The dolerite-sill comes also to view along the floor of the upper course of the Kuja within the area of the Kisii Highlands.

Skirting the western base of the escarpment, I crossed the Kuja again by a ford at the altitude of 4441 feet: that is, only 94 feet above the level of the river at the Sakwa bridge, $6\frac{1}{2}$ miles lower down, thus revealing a very gentle gradient for this part of its course. The rock is here an extremely-rotten sericitic chlorite-schist,[2] with foliation directed 60° south-south-westwards, and it was difficult to obtain even a moderately-fresh specimen.

[1] The rock consists of a fine felt of laths of plagioclase (oligoclase-andesine, Ab_5An_3), together with granular, very pale-brown augite. In a more deep-seated specimen from the Vinyo Gorge the augite is subophitic, and has become replaced by chlorite. Ilmenite has become completely altered to leucoxene, and there is some interstitial chlorite, probably representing an altered glassy base. Fine aggregates of small quartz-granules, with interstitial vermicular chlorite, occur in irregular nests (especially along zones), and have probably been derived from the absorption of the overlying quartzite. The rock near the junction becomes full of amygdales of quartz ($\frac{3}{4}$ inch or less in diameter), either chalcedonic containing spherulitic chlorite centrally, or else an aggregate of quartz-grains with a lining of chlorite. Other amygdales may consist of a nucleus of pyrite surrounded by epidote, and this in turn by chalcedony. Pyrite also occurs in irregular masses bordered by hæmatite. Much-altered specimens of the junction-rock become essentially a quartz-epidote rock with chlorite.

[2] The schistosity of the greenish-grey rock with silky foliation-planes is due to very fine flakes of sericitic mica and chlorite. The numerous 'eyes,' occurring down to small dimensions, are composed of very fine aggregates of spherulitic chalcedony and chlorite, and are wrapped round by chlorite and sericite. In some cases such aggregates show prismatic outlines, as if pseudomorphous after felspar-crystals with their long axes nearly normal to the foliation-planes.

A specimen of rock taken a little farther on, within the Kuja Gorge (Pl. XXIII, fig. 1), just before one comes to the dolerite itself, helps to explain the original character of these decomposed schists. An outcrop of a very compact pale-grey rock, with a strike of north by west, occurs at a distance of a mile (measured transversely to the strike) from the schist at the ford. It is a spherulitic quartz-porphyry,[1] which has undergone some crushing and alteration, becoming a so-called sericite-porphyroid. Perhaps the schists of the Kuja Ford are to be regarded as the marginal and more extensively-crushed modification of the original quartz-porphyry, with the usual increase of sericite, or as the crushed tuffs of the quartz-porphyry. The actual contact of the dolerite-sill with the ancient quartz-porphyry could not be observed, owing to the thickness of red soil.

In order to make an examination of the quartzite south of the Kuja Gorge at Vinyo, I ascended the rounded slopes of the dolerite extending up to the precipices of the well-bedded quartzite, which is 500 to 600 feet thick. Although I searched diligently for fossils, it was a fruitless task; but the exposures of bare rock were so numerous along the edge of the escarpment, and the section from the base of the cliff up to the summit was so readily accessible, that I could hardly have failed in my search if any fossils had been present. The rock is, on the whole, very uniform, consisting of well-bedded quartzitic sandstone, weathering in large slabs, with streaks of hæmatite along the bedding-planes and joints. Half way up the cliff I collected a piece of a slab showing sun-cracks; ripple-marks were abundantly present at all levels, and occasionally impressions of raindrops and worm-tracks were visible. Current-bedding is prevalent, and sometimes there is a zone of a fine conglomerate containing quartz-pebbles (up to $\frac{3}{8}$ inch in longest diameter). The dip varies here from 5° to 10° west-south-westwards, and the prevalent direction of the ripple-marks was west-south-westwards and east-north-eastwards, indicating a gentle current from the south-south-east; but I also observed the

[1] The rock is pale grey, compact, but slightly schistose, somewhat waxy in lustre, and contains a few scattered, small, grey quartz-grains. Under the microscope the quartz-phenocrysts present all the usual characteristics of a typical quartz-porphyry: as, for example, the corroded and lobed appearance and the inclusions of ground-mass (now altered to fine aggregates of white mica); the quartz encloses an occasional flakelet of biotite, and shows strain-shadows; a hexagonal cross-section is present. Tourmaline occurs in a few thin, pale indigo-blue strings, showing some parallelism and in one case bordering a quartz-crystal. Under crossed nicols the ground-mass (but slightly dusky in comparison with the quartz-crystals) is resolved into a mosaic of mutually interfering spherulites, considerably cracked, and showing tiny flakelets of sericitic mica along the innumerable cracks; even the felspathic portion seems to have altered into quartz and sericite. While most of the spherulites are greatly shattered and cracked, a few are comparatively intact, with white mica sweeping round them. Sericitic aggregates also occur in strings between spherulites, and probably represent some of an originally glassy base. The radial selvage enveloping a corroded quartz extinguishes simultaneously with it, and in optical continuity.

directions west and east, north-west and south-east, and north-north-east and south-south-west. Crossing the plateau (here reduced by erosion to a width of only 6 furlongs) from the escarpment eastwards until I overlooked the upper course of the Kuja, I descended near Kenin, returning to the Kuja Gorge. The angle of the slope immediately below the nearly-vertical cliff is as high as 65°. Near the junction with the dolerite the buff-coloured quartzitic sandstone, veined and blotched purple with hæmatite, becomes changed to a snow-white quartzite, and the dolerite is here highly amygdaloidal with amygdales of quartz (as already described), and decomposes into a thick mantle of fertile red soil. The cone of Kinsunsi on the right bank of the Kuja, near the western exit of the gorge, is an apophysis of the sill or laccolite, and is surrounded by an aureole of white quartz.

It seems natural to assume that these quartzites belong to the same series as the quartzites of the Nandi Hills on the north side of the Kavirondo Gulf; but they are far more uniform in character than the Nandi Quartzites described by Mr. G. F. Scott-Elliot & Prof. J. W. Gregory [1] as belonging to the Karagwe Series, which is so much more extensively developed on the western side of the Victoria Nyanza, where it reaches a thickness of over 1200 feet. The quartzite belongs to the uppermost division of the Series, which has been traced to the southern end of Tanganyika and is probably of the same age as the Waterberg Series of the Transvaal: that is, presumably Devonian.

The quartzitic sandstones of the Kisii Highlands have not been subjected to the pressure which has tilted up the Karagwe Beds to a high angle, and crushed them until they are highly contorted. If it were not for the intrusion of the underlying dolerite, these Kisii sandstones would doubtless have still preserved their original horizontality.

Crossing the Kuja as I proceeded on my march to Kisii Boma, I found the ford in the centre of the gorge to lie at an altitude of 4894 feet. Comparing this with the altitude of the ford outside and below the gorge (that is, 4441 feet), we find a fall of 453 feet in $2\frac{1}{2}$ miles, or a gradient of 1 in 29, accounting for the numerous rapids of the Kuja in its rocky bed through the gorge. This gradient stands in marked contrast with the lower and succeeding stretch to the Sakwa bridge (only 94 feet in $6\frac{1}{2}$ miles).

In addition to the evidence of the rejuvenation of the river, as shown by the very frequent rapids and waterfalls, the angles of slope of its valley yield further support to this conclusion. From the 65° of the quartzite immediately below the precipices of the edge of the plateau the angle rapidly changes to a long slope of 10° over the easily-decomposed dolerite, and, on approaching the river, it suddenly alters to a short slope of 30° (cut also in the same dolerite) down to the present bed of the river.

If one keeps a northerly direction over the nearly-level summit

[1] 'The Geology of Mount Ruwenzori' Q. J. G. S. vol. li (1895) pp. 677, 678.

of the quartzite-plateau (over 6000 feet high) the view to the westward over Kitembe shows its flat-topped outliers above the gneissic peneplain at their foot, and the west-south-western slope of their surface is a dip-slope. Turning thence north-westwards, I left the Kuja basin and descended to the Yawi River (a tributary of the Riana), over white quartzite down to the amygdaloidal dolerite, here exposed over a wide surface; and the symmetrical cone of Saria marks another apophysis, with an aureole of white quartzite, similar to the occurrence of the Kinsunsi cone. From Saria a steep descent to the Nyanchoba led to the basement-floor of pink granitic biotite-gneiss[1] below the dolerite: it decomposes to a red-brown soil.

Crossing a bastion of the doleritic plateau of Merinde, I descended again to the biotite-gneiss, traversing a wide valley (tributary to the Riana). On its northern slope, just at the western foot of Nyachwa, the gneiss is directly overlain by the dolerite, which shows massive jointing and no signs of flow or columnar structure. This doleritic spur of Nyachwa forms the left side of the valley of the Riana, with its gold-bearing sands. Kisii Boma, the present centre of administration, lies on the lower northern slopes of Nyachwa, at the height of 5705 feet. On the summit, I noticed firmly embedded in the dolerite a lump of white quartzite (12 × 6 inches): this had doubtless been floated off by the intrusive dolerite from its overlying cover of quartzite, which has been long ago denuded away. Probably the dolerite never reached the surface when molten, but insinuated itself as a sill beneath the ancient sandstones, which must have extended far to the west and north beyond their present limits.

During the two days which I had to spend at Kisii Boma before returning to the lake-shores, I marched across to the Manga Escarpment, which stretches in commanding cliffs far to the north-north-east (Pl. XXIII, fig. 2). The lower ground at its base comprises the thickly-populated district of Kitutu in the basin

[1] The rock encloses numerous allotriomorphic crystals (measuring up to 7 mm. in longest diameter) of microcline-microperthite with perthitic network and Carlsbad twinning, quite fresh and slightly dusty, and often outlined with hæmatitic dust; occasional inclusions of biotite, plagioclase, and quartz-granules, and sometimes thin veins and blebs of green hornblende. Plagioclase (andesine, Ab_3An_2) is also present in smaller crystals (up to 4 mm.), with a tendency to idiomorphism; often it is turbid centrally with flakelets of white mica, zoisite, epidote, and calcite, and occasional patches and thin veins of secondary hornblende, but showing cleared margins of secondary felspar in optical continuity—sometimes enclosing quartz-granules. Biotite (up to 2 mm.) is fairly abundant, often greenish, enclosing apatite and zircon, and associated with magnetite; it is altering to chlorite, epidote, and lenticular aggregates of carbonates—in one case a sagenite-web is evident. A few prisms of brown hornblende are present, on which biotite is moulded. Magnetite and sphene are also accessory, and a small grain of kyanite was observed. Quartz is rather abundant and interstitial, mostly in large grains containing strings of minute fluid inclusions; it is occasionally brecciated marginally, but shows only a slight degree of undulose extinction; sometimes it encloses isolated flakelets of white mica.

of the Megusi River, and is composed of the same sill of dolerite as that which occurs at the base of the Vinyo Escarpment. As one approaches the cliffs, about 700 feet high, of the Manga Escarpment, it is soon evident that they consist of the same current-bedded quartzitic sandstone as at Vinyo, much stained and blotched with crimson hæmatite, and frequently displaying ripple-marks and impressions of raindrops, as also an occasional streak of quartz-pebbles. A close search for fossils was equally fruitless. Here, however, the dip is 12° south-south-eastwards, while at Vinyo it was 10° west-south-westwards: from my lofty standpoint (6388 feet) it certainly seemed to me that the intervening strata had been raised into a low dome by the intrusive dolerite. For this reason, the intrusion may, perhaps, be regarded rather as a laccolite of low curvature than as a sill. The hæmatitic staining seems to have proceeded from below, rising up the vertical joints and extending along the bedding-planes: it was, not improbably, due to pneumatolytic action accompanying the intrusion of the dolerite. Wherever the iron-oxide is most evident the weathering is greatest, and even swallow-holes (6 feet in diameter) occur near the edge of the precipitous escarpment.

The view to the south and east shows that the Kisii Highlands form an extensive plateau of quartzitic sandstone, greatly dissected by the Kuja and its tributaries flowing southwards, as well as by the Northern Awach (the Awach Mateni) flowing northwards. The plateau culminates in the distant heights of Chamonyeru (7068 feet) in the east.

The edge of the escarpment is itself a watershed between the basins of the Kuja and the Megusi (a tributary of the Southern Awach or Awach Madoung). The eastern streams which drain the escarpment and flow to the Kuja are very chalybeate, deriving the iron from the hæmatite of the quartzite.

After leaving Kisii Boma on my march west-north-westwards to Homa Bay, I left the dolerite behind at Nyachwa, and entered again on the peneplain of biotite-gneiss which extends across the deep Riana Valley, rising northwards in the rounded bluff of Meriba and stretching up to the Kona Plateau and watershed, whence the rivers run directly northwards to the Kavirondo Gulf. This part of the old plateau, 12½ miles from Kisii, is composed of a crushed, pale brownish-grey porphyry,[1] showing similarity with the Vinyo quartz-porphyry. It weathers readily to a yellow-

[1] The rock consists of a dusky mosaic of quartz-grains, with interstitial sericite, as in the Vinyo rock; and, although the spherulitic structure is not so well marked, some instances can still be made out containing a nucleus of sericite flakelets, but there has been considerable recrystallization: all the felspathic constituent of the spherulites and ground-mass seems to have been altered into quartz and sericitic mica. No phenocrysts are present, but there are numerous small mossy aggregates of limonite. The rock has been much fractured and veined by a mosaic of clear interlocking quartz-granules; and, where the crack has fractured one of the dusky quartz-grains, the clear quartz of the vein is in optical continuity with it.

brown sandy soil, and the wide valley of the Nyakuru which traverses this rock only shows gentle rounded slopes of 8°.

The summit of the plateau at the 13th mile from Kisii consists of a pink granitic biotite-gneiss[1]; but the porphyroid soon reappears, weathering to a depth of over 6 feet of yellow sand. Apparently overlying it occurs a small outcrop of a greenish-grey chloritic calc-schist.[2]

On descending from the Kona Plateau, one notes that the rock at the 14th mile from Kisii (before coming to Sori Kodongo), becomes highly schistose and mylonitic, consisting practically of very fine mosaics of quartz with sericitic mica and much limonite, readily decomposing to a reddish-brown sandy soil. It is, perhaps, the greatly-crushed marginal modification of the porphyroid, forming a parallel to the sericitic schists of the Kuja Gorge below Yinyo. As I proceeded, I found the underlying rock to be extremely ferruginous, weathering so deeply that no fresh rock could be reached. Much murram has formed in patches, as it always does where there is much iron in the soil. Numerous veins of quartz, a foot thick, run in a north-westerly and south-easterly direction: that is, in the same direction as the strike of the gneisses and schists, and in evident relation to the earth-movements that have affected this district. The low rounded ridges in this area belong to the amphibolite-group, but the rocks are altered and decomposed to an excessive degree.

Shortly before one gets to Langueh, the rock is seen to be a greenish-grey fine-grained epidote-schist,[3] probably a much-altered amphibolite, and half a mile farther on the very dark-green

[1] The rock contains numerous allotriomorphs (measuring up to 7 mm. in longest diameter) of orthoclase (microperthite) with microperthitic interpenetration; it is turbid with dusty decomposition-products, flakelets of white mica, etc., and hæmatitic dust. Plagioclase (oligoclase-andesine, Ab_2An_1), also somewhat decomposed, is subordinate. Quartz is abundant in separate grains (up to 3 mm.), as well as in granophyric intergrowths with the felspars; it is much cracked, and sometimes brecciated marginally; it contains some biotite and also calcite. Biotite (up to 2 mm.) is somewhat sparse; it encloses magnetite, and has been entirely altered to chlorite (partly spherulitic and exhibiting the usual blotchy pleochroism), with epidote, calcite, and some hæmatite. Sphene bordered with hæmatite is accessory, and calcite occurs along cracks.

[2] The rock is mainly composed of aragonite and spherulitic chalcedony in alternating zones, with some chlorite and much sericitic mica in interstitial aggregates. Numerous small curved markings are present, circular, ellipsoidal, or kidney-shaped, and in some cases somewhat compressed and drawn out, all approximately of the same size; they are evidently anterior to the formation of the chalcedony or the white mica, which traverses them independently. They are finely granular on the concave side, bluish black by transmitted and white by reflected light. They somewhat recall the tests of *Cypris*, but Prof. Bonney, who has kindly examined the slide, considers them to be merely extraneous matter thrust outwards during the formation of the spherulitic chalcedony.

[3] This rock consists of schistose aggregates of epidote and quartz-granules, pistacite and zoisite, and some yellow-green serpentinous mineral showing aggregate polarization. Much limonite is present in strings and patches. The rock has been considerably fractured and veined with quartz.

compact rock may be termed a zoisite-hornstone[1]: it is probably an amphibolite that has been altered by the intrusion of a neighbouring diabasic rock, also greatly altered and deeply weathered, but possibly a teschenite[2] originally. The last-named rock crops out of the weathered débris at less than a mile from the outcrop of the altered rock, and occupies the Rungwe Valley at Langueh, a little Indian trading-station, 18 miles from Kisii Boma.

From the Kona Plateau there had been a slow but steady descent, although the view to the eastward was blocked by low hills and ridges, probably of amphibolites; but beyond Langueh (4651 feet) these hills flattened out, and on the north and north-west lay a nearly treeless and extensive volcanic plateau, traversed only by shallow valleys extending north-eastwards towards the Kavirondo Gulf. Between Langueh and the Ogweyo River, the low south-westerly and north-easterly ridges are composed of a dark-green tuff[3] derived from a rather acid andesitic lava; I did not, however, find this lava *in situ*.

The summit of this lower plateau is composed of the nepheline-basalt already described (p. 141), which probably flowed out from Ruri or Gembe as a centre, and the remainder of the country as far as Homa Bay is occupied by this basalt and its tuffs (see p. 143).

[1] The rock has a pitchy lustre and splintery fracture, and presents a somewhat brecciated appearance. Larger clearer patches, usually with prismatic and rectangular outlines, are composed of a mosaic of quartz-granules, flakelets of white mica and interstitial chlorite, and may be pseudomorphous after felspar. Other aggregates consisting of zoisite and quartz show outlines recalling hornblende. Zoisite is abundant, and is honeycombed with quartz, presenting a micropœcilitic appearance; the largest of the zoisite-crystals are prismatic, in a radiating sheaf. Small specks of kaolin are frequent, and nests of epidote and calcite occur scattered in the rock, which is traversed by thin veins of quartz and epidote.

[2] The rock contains abundant crystals (measuring up to 4 mm. in longest diameter) of plagioclase (acid labradorite, Ab_1An_1), mostly of prismatic habit, very turbid and decomposed, largely replaced by flakelets of white mica, and traversed by numerous cracks filled with chlorite and occasionally epidote; there is an instance of a granophyric intergrowth of turbid felspar and quartz. Colourless augite (malacolite) occupies the bulk of the slide, having crystallized later than the felspar, in aggregates of allotriomorphic crystals (measuring up to 3 mm. in longest diameter) with a tendency to form long prisms; it contains small diallagic rods; it is sometimes twinned and intergrown in a pegmatitic manner, so that a fresh crystal may be intergrown with a uralitized crystal. Zeolitic pseudomorphs, possibly after elæolite, are pale brown and minutely fibrous, polarizing like moiré silk in low greys and extinguishing parallel to the fibres; they enclose small patches of augite in a pegmatitic intergrowth, especially centrally. Some clear secondary green hornblende is present, developing at the expense of the augite, and is associated with some quartz. Apatite and magnetite are accessory.

[3] The rock is compact and very fine-grained: numerous fragments of crystals are present, but all of very small dimensions:—Abundant plagioclase (oligoclase-andesine, Ab_3An_2); a little orthoclase; many angular fragments of very pale-green diopside, quite fresh and free from inclusions, sometimes exhibiting lamellar twinning; numerous microlitic felts of oligoclase, colourless augite-granules and interstitial glass; and lapilli of brown dusty glass with zeolites filling the steam-cavities. Chlorite is abundant interstitially, and a subordinate amount of zeolite and calcite is present.

At the base of the valley of the Agulu Muk, the river-gravels overlie a rotten rock resembling a quartz-porphyry; and at the south-eastern corner of Homa Bay the hills of Najanja (rising to 4451 feet, and trending from north-west to south-east) form an important physical feature. They are built up of a purple quartz-porphyrite,[1] probably part of the same mass. In places the porphyrite is traversed by quartz-veins, and forms rounded hills and ridges; it weathers to a red-brown soil.

Crossing this spur of quartz-porphyrite, I found that its eastern slopes were bordered by a low selvage, 300 yards wide, of banded gypsum, layers of pure gypsum (usually $\frac{1}{4}$ inch, but sometimes as much as an inch thick) occurring in frequent alternation with yellow-brown argillaceous layers of similar thickness. The outcrop has a general north-westerly and south-easterly strike, dips 10° south-south-westwards, and shows a bare fretted surface. Many loose blocks are lying on the surface, tilted in all directions. It is probably of the same age as the presumably Pliocene beds, which I found north of Homa Mountain (see below); but this area must have been separated and shut off from the Nyanza, to form a lagoon without an exit.

My course lay north-eastwards across the alluvial plain, about 4 miles wide, of the Southern Awach or Aloychi River, from which isolated cones of basalt, as, for instance, Uchimbo and Chamanga (or Chanvanga) rise abruptly with slopes of 30° to 40°. A thick envelope of regur covers the northern part of the plain. On passing Chamanga, one notes that the ground rises slightly at the village of Kumgendia to form a low rounded ridge, about 2 miles wide. The rock does not crop out at the surface, but the purplish-brown sandy soil is probably derived from a rock similar to the quartz-porphyrite of Najanja.

The northern slope is steeper, and the path to Kendu passes between a low hill of basalt on the west and the basaltic cone of Orian (Rabur) on the east. Pebbles of quartz, jasper, and hæmatitic quartzite (like that of the Kisii Highlands) lie scattered on this slope, and perhaps indicate the old lake-beach at about 4000 feet, to which I have already referred (p. 146).

Another alluvial plain (also covered with black earth) extends for about 4 miles to the Northern Awach; while on the west it is bordered by an outspur from Homa, ending in a low scarped bluff:

[1] The rock has a splintery fracture, and contains somewhat melted-down phenocrysts (up to 4 mm.) of plagioclase (oligoclase-andesine, Ab_5An_3) which enclose occasional particles of green augite and little patches of a pale-green serpentinous aggregate; some pericline-twinning occurs. The quartz-phenocrysts (up to 7 mm.) are corroded and lobed in the typical manner, but also show a few hexagonal sections; they moreover enclose circular patches of the serpentinous aggregate: a very narrow, radiate, quartzose selvage borders the quartz-crystals, but is absent round the felspars. Minute crystals of pale-green augite occur very sparingly. The ground-mass is dusty, quartzose, sometimes microspherulitic, containing abundant microlites and needles of oligoclase and occasionally small aggregates of quartz-granules. The pale-green serpentinous aggregate also occurs disseminated in the ground-mass, and probably represents original glassy matter. Hæmatite-dust imparts to the rock its reddish colour.

this consists of a flow of phonolite,[1] overlying a cellular, yellowish earthy, calcareous tuff, much veined with calcite, and containing fragments of nepheline-crystals, a little biotite, some magnetite-granules, and a little zeolite. It is somewhat reddened and baked near the plane of contact.

Between the Northern Awach and the Kavirondo Gulf at Kendu is a hill of brown clay, its low slopes measuring no more than 5°. As we reach the summit, a crater-lake, Lake Simbi (Pl. XXIV), is suddenly disclosed to view, slightly elliptical in outline, the long axis running west-north-west and east-south-east and measuring about three-quarters of a mile, while the width of the lake is a little more than half of this. The river rises to between 70 and 100 feet above the surface of the lake, which stands somewhat below the level of the plain of the Awach on the south, but slightly above that of the Nyanza on the north.

The solid rock only appears in two places on the south-western shore, and consists of the micaceous sandstone which I subsequently found well developed along the coast west of the Awach. Elsewhere, the rim of the lake is composed of a brown clay dipping everywhere away from the centre of the lake at an angle of 30° to 40°. In places the clay contains blocks of gneiss (which occurs *in situ* only a couple of miles away to the east) and pebbles of quartz, but in no case were there any fragments of lava. On the edge of the eastern rim I found a block of travertinous limestone, measuring $3 \times 1\frac{1}{2}$ feet, containing a fragment of bone, and clearly belonging to the same series as the Pliocene beds west of the Awach (see below, p. 158). This block was indurated, and presented the appearance of having been subjected to heat. The outward dip of the clay of the lake-margin conveyed the impression that Lake Simbi marks the site of an explosion-crater similar to those of the Eifel. Probably it was formed within the memory of man, for the natives told me of a legend that its site was once occupied by a hill crowned by a homestead belonging to a very wicked chief, and that it was destroyed and disappeared in a single night. The water of the lake is yellow-green, due to the presence of confervæ, and jelly-like lumps of an emerald-green *Nostoc* occur along the margin. It is strongly alkaline and also bitter, with the fishy taste of carbonate of soda.[2]

[1] The rock is pale grey, compact, and fine-grained, exhibiting irregular fracture and a honeycombed surface, with some indications of lines of flow; occasional white felspars (up to 4 mm.) are visible. Under the microscope the felspar (sanidine) occurs in a few large phenocrysts with occasional Carlsbad twinning, but it has been much altered to a soda-zeolite. The ground-mass consists of a very fine-grained felt of abundant small nepheline-crystals, sanidine-microlites and granules, and needles of very pale-green augite in mossy aggregates and patches stained brown by iron-oxide, in a glassy base.

[2] Prof F. Stanley Kipping, F.R.S., has kindly examined my sample of the water, and informs me that, while sodium carbonate is the main component, iron salts, together with sulphates and silica, are present in appreciable quantities; smaller quantities of calcium and magnesium salts and phosphates are also present.

A thin crystalline crust is deposited round the shore, and has essentially the same composition as the water. It is gathered by the natives in baskets for mixing with their food, and for treating their tobacco. I noticed a similar efflorescence of soda on the borders of the Kimera swamp, north of Homa Mountain. The water is gradually rising, as shown by some half-immersed, dead candelabra euphorbias, already standing 10 feet away from the shore.

West of the mouth of the Awach River, the ground rises to form a terrace running east-south-eastwards and west-north-westwards, about a mile wide, between the Nyanza and the Kimera swamp; and it faces the Nyanza in a cliff about 30 feet high, flattening out again on the west. The lake has now retreated for about a quarter of a mile from the base of the cliff, which is cloaked at its foot by talus. The downward succession of the beds (dipping 5° north-north-eastwards), as revealed in the cliff, consists of:—

	Thickness in feet.
(1) Grey or pale-buff argillaceous sandstone, with small flakes of biotite and larger plates of greenish talc, also markings of dendritic manganese; current-bedded and coarser-grained than the lower beds. It contains pebbles of quartz up to three-eighths of an inch long. Calcite occurs along the bedding-planes.	5
(2) Brown, shaly, sandy clay	3
(3) Hard argillaceous sandstone, in thin beds alternating with shales	3
(4) Brown shaly clay, often wedging out	3
(5) (Base not seen.) Argillaceous current-bedded sandstone. Coarse beds, alternating with finer	10

A large surface of bare rock is exposed on the summit of the broad stony terrace, and the beds, instead of showing a plane surface, appear in gentle undulations, giving rise to a number of shallow basins. No ripple-marks are visible anywhere, and not a trace of any fossils. On the terrace the dip changes in the southern part to 5° south-westwards, whence we may infer that the terrace itself is a low anticline.

Farther west, only Beds 2 and 3 are visible in the cliff, which flattens out and finally becomes quite grass-grown. After some interval, another group of strata appear, evidently at a slightly higher horizon than the above-described series, but the actual junction was not visible. The cliff shows:—

	Thickness in feet	*inches.*
Recent soil	1	0
Gravelly grey clay	2	0
White calcareous travertine	0	6
Greenish-grey clay	1	0
(Base not seen.) White calcareous travertine in undulating beds, with tusks of elephant, bones of zebra, antelope, etc.	3	0

Still farther west, near a very big sycamore fig-tree, which forms

a landmark, this travertine is more fully exposed over a wider area. Here the succession consists of:—

	Thickness in feet	inches.
(1) Greenish-grey sandstone, with bones of baboon.	2 to 6	0
(2) Grey gravelly clay, with streaks of sand and gravel	3	0
(3) White calcareous travertine, with bones of *Elephas* aff. *meridionalis*, *Hippopotamus*, *Phacochœrus*, and antelope[1]	6 ins. to 1	6
(4) (Base not seen.) Greenish-grey clay	4	0

The beds have been thrown into a broad syncline; for, in the western part of the exposure, they dip 20° south-south-eastwards, and in the eastern part (about 150 yards distant) they dip 50° north-north-westwards. These directions differ altogether from those observed in the sandstone cliff 5 miles away to the east, but it is probable that they are due to a local subsidence, perhaps caused by the leaching-out of underlying soda-beds, for there is still a strong efflorescence of soda on the surface of the beds of clay, and the crust is continually collected by the natives, as at Lake Simbi.

These beds are probably of late-Pliocene age, and they may be compared with the beds found north of Lake Rudolf, in the lower course of the Omo River, by E. Brumpt[2] in 1903, containing, among other bones, *Hipparion* (near to the Pliocene *H. lybicum*), *Hippopotamus*, *Rhinoceros*, *Phacochœrus*, *Buffelus*, *Camelopardalis*, antelopes, and *Elephas* cf. *meridionalis*. A tooth of *Dinotherium* was also recorded from these beds; but, either it is a Pliocene species, or it may have been derived from some earlier beds similar to the Karungu Miocene Series. The uppermost stratum consisted here of gypsum, and I have already suggested that the gypsum beds of the south-eastern angle of Homa Bay probably belong to the Pliocene Series north of Homa Mountain.

A rounded spur of hornblende-biotite-gneiss rises out of the low-lying country east of Lake Simbi, and this granitic gneiss,[3] which shows a more marked cataclastic structure than any

[1] These fossils will shortly be described by Dr. C. W. Andrews in a future paper.

[2] E. Haug, 'Traité de Géologie' vol. ii, pt. 3 (1911) p. 1727.

[3] The rock contains abundant allotriomorphs (up to 8 mm.) of plagioclase (oligoclase-andesine, Ab_5An_3), in which the fine twinning is often repeatedly bent; only traces of zoning are present, and decomposition-products (white mica, calcite, epidote, and zoisite) occur centrally. Orthoclase is less in quantity and in smaller grains (up to 4 mm.), usually turbid centrally. Green hornblende (up to 3 mm.) is fairly abundant (α, pale straw; β, olive-green; γ, blue-green), sometimes twinned, occasionally bent; it is especially associated with quartz and some may have recrystallized; occasionally with epidote and calcite centrally. Biotite is rather sparing, and has altered either to chlorite or to a mixture of chlorite, epidote, and zoisite; it has been much crinkled and contorted, encloses apatite, and is associated with magnetite and sphene. Magnetite occurs in a few crushed grains, and several pinkish-brown crystals of sphene are present. Quartz is abundant, very much crushed and rolled out into lenticular masses; the grains show denticulate margins and undulose extinction, with strings of inclusions.

of the other gneisses of which I collected specimens, and is probably older in date, stretches far away to the east-north-east through the districts of Nyakongo and Nyakach. South of this gneissic area lie the slates of Wire Hill (a conspicuous flat-topped hill rising to 5276 feet), but I was unable to examine them. Their distribution is approximately indicated in a sketch-map (which Mr. C. W. Hobley kindly allowed me to examine) made by Mr. J. S. Coates, Government Geologist, in 1909. He designates these slates the Wire Hill Beds, and they appear to be associated in places with chalcopyrite in quartz and graphite, according to information kindly given to me by Mr. G. R. Chesnaye. Probably they belong to the same series as the schists at the base of the Vinyo Escarpment, but their relations to the gneiss are as yet unknown.

Appendix I.

Abridged Statement of the Downward Succession of the Miocene Beds at Nira, with Indications of the Points of Difference from the Outcrops at South Nira, West Kachuku, Kachuku, East Kachuku, and Kikongo.

Upper Series (Nos. 1–12).

Beds.		*Thickness in feet.*
No. 1.	Grey clays with calcified tree-stems, overlying a greenish-grey conglomerate, passing down gradually into argillaceous sandstone	8
No. 2.	Pale greenish-grey clay, with seams of brown shales	8
No. 3.	Brown clay, with thin seams of shale; northwards the clay becomes grey. At East Kachuku and Kikongo Nos. 2 & 3 consist of grey current-bedded sandstones, containing biotite and augite	9
No. 4.	Pale-grey clay. At East Kachuku it becomes an argillaceous sandstone	8
No. 5.	Hard grey clay, passing (at South Nira) into sandstone containing biotite and augite. At Kachuku it contains *Ampullaria ovata* and crocodiles' teeth	$2\frac{1}{2}$
No. 6.	Soft grey clay	$2\frac{1}{2}$
No. 7.	Pale-brown clay with septarian nodules; eastwards it becomes shaly	3
No. 8.	Grey calcareous sandstone, with thin seams of grey clay. At Kikongo it is current-bedded, containing augite and enclosing a few land-shells (*Tropidophora nyasana*, *Limicolaria*, and *Cerastus*)	6
No. 9.	Thinly-bedded grey clays and brown shales. At Kachuku and Kikongo the clay alternates with thin seams of travertine, and at Kikongo the lower part contains seams of grey sandstone	7
No. 10.	Brown clay. At Kachuku and Kikongo it consists of grey clay, with thin seams of travertine	5
No. 11.	Grey clay. At South Nira the upper foot is a massive grey sandstone	5
No. 12.	Brownish-grey clay yielding a river-crab (*Telphusa*) and scutes of crocodile. At South Nira and Kachuku are numerous seams of shale. At Kikongo the lower half consists of grey sandstone	$4\frac{1}{2}$

Middle Series (Nos. 13–25).

		Thickness in feet.
No. 13.	Yellow-grey clay containing large plates of biotite; it yields *Trionyx*, *Testudo*, and Artiodactyls. Eastwards it becomes greenish-grey, with a discontinuous seam of white or pink calcareous concretions	$5\frac{1}{2}$
No. 14.	Dull-red marlstone, travertinous in places. It becomes greenish grey at Kikongo. It contains many casts of *Ampullaria ovata* (with opercula) and of *Lanistes carinatus*, as also *Trionyx* and other Chelonian remains. This bed forms a very definite and constant horizon	$0\frac{1}{2}$–$1\frac{1}{2}$
No. 15.	Red or grey clay, with a marlstone like No. 14 in the upper half, containing similar fossils, Artiodactylian *(Prodromotherium)* and Crocodilian remains. Thin layers of calcareous concretions in the lower half	$5\frac{1}{2}$
No. 16.	Grey sandstone, with a thin median seam of grey or red clay. At Kachuku it contains mandibles of small Hyracoids *(Miohyrax)*, *Trionyx*, crocodile, *Ampullaria ovata*, and *Cleopatra exarata*	1
No. 17.	Grey or red clay, passing down into grey sandstone which contains (at Kachuku) crocodile, *Trionyx*, and *Ampullaria ovata*	1
No. 18.	Red and grey mottled clay, sometimes with thin seams of sandstone or (at Kachuku, where it thickens to $3\frac{1}{2}$ feet) of travertine	1
No. 19.	Grey sandstone with *Ampullaria ovata*, passing down into red clay which (at Kachuku) contains inconstant seams of mudstone. The lowest bed at Kachuku contains Chelonian and Crocodilian remains, together with *Cleopatra exarata*	2–3
No. 20.	Grey current-bedded sandstone passing down into red clay with seams of travertine, containing Chelonian, Crocodilian, Rhinoceros, and Proboscidean remains	4–5
No. 21.	White, current-bedded, calcareous sandstone, becoming argillaceous below, and containing *Cycloderma victoriæ*, *Ampullaria ovata*, *Lanistes carinatus*, *Burtoa nilotica*	2
No. 22.	Pale-grey current-bedded sandstone, becoming gravelly below. At Kikongo Nos. 21 & 22 are represented by grey clay. At Kachuku the latter bed contains a large Proboscidean tibia (perhaps of *Dinotherium*), Chelonian remains *(Podocnemis)*, and *Ampullaria ovata*	2
No. 23.	Grey sandstone passing into conglomerate. At Kachuku it is markedly calcareous	$0\frac{1}{2}$
No. 24.	Orange-coloured sand yielding teeth of *Protopterus*, crocodile, *Dinotherium*, small rodents (aff. *Phiomys*), etc., overlying a greenish-grey clay with *Ampullaria ovata* and *Cleopatra exarata*. At Kachuku this clay also contains *Achatina*. A thin travertine or travertinous sandstone yielding Chelonian remains forms the base	$1\frac{1}{2}$
No. 25.	Grey argillaceous gravel, overlying a red and grey mottled clay with Chelonian remains	2

Lower Series (Nos. 26–37).

No. 26.	Buff-coloured, nodular, current-bedded sandstone, with remains of *Trionyx* and crocodile	$0\frac{1}{2}$–1
No. 27.	Grey, argillaceous sandstone, sometimes passing laterally into a coarse gravel composed of pink gneiss, green andesite, quartz, jasper, and grey sandstone (from an older bed); it contains fragmentary remains of *Trionyx* and crocodile, with coprolites	3

		Thickness in feet.
No. 28.	Hard, buff-coloured, nodular sandstone. At Kachuku it becomes a coarse calcareous conglomerate	$0\frac{1}{2}$
No. 29.	Yellow argillaceous gravel, with intercalations of greenish-grey clay or of yellow sandstone. It is a calcareous gravel at Kachuku, containing Chelonian remains and a fragment of a tusk	3
No. 30.	Conglomerate of rounded calcareous nodules (up to 2 feet in diameter) in a calcareous cement, each nodule showing concentric coats. It passes sometimes into a hard buff-coloured sandstone, and forms a very constant horizon...	2
No. 31.	(*a*) Upper part (beds i & ii), 4 feet. Grey clay, with seams of sandstone and gravel, containing teeth of *Dinotherium* and bones of Anthracotheres (*Brachyodus* etc.). (*b*) Middle part (beds iii–vii), 3 feet. Grey or brown clay, with seams of reddish-brown marlstone containing *Ampullaria ovata.* At Kachuku it becomes a current-bedded sandstone with a discontinuous seam of brown marlstone, containing a Proboscidean scapula and the mandible of a Carnivore *(Pseudælurus africanus)* (at West Kachuku). (*c*) Lower part (beds viii–xv), 13 to 18 feet. Brown clay, with inconstant seams of calcareous conglomerate in the upper part. In the lower part it consists of grey clay which yields *Cleopatra bulimoides* and *Ampullaria ovata*, alternating with thin seams of current-bedded sandstone. Eastwards this division becomes more arenaceous, until at Kachuku it consists of two zones of lenticular beds of gravel, separated by 4 feet of buff-coloured current-bedded sandstone. The Upper Gravel Zone is the chief depository of bones of *Dinotherium hobleyi* (mandible, femur, humerus, tusk), bones of Anthracotheres, allied to *Hyopotamus* (large humerus and tibia of *Brachyodus*, mandible of *Merycops*, *Merycopotamus*, etc.), Rhinoceros, a Carnivore (*Pseudælurus africanus*) and a Creodont, giant tortoise (*Testudo*), *Trionyx*, crocodile, and *Cerastus* cf. *mœllendorffi.* In the Lower Gravel Zone only shattered Chelonian remains occur, and seams of travertine become dominant. The base of this division is not visible at Kachuku, although present at West Kachuku .	20–25
No. 32.	Dark-brown ferruginous marlstone yielding *Cleopatra bulimoides*, *Ampullaria ovata*, and *Lanistes carinatus.* Passes eastwards into a quartz-ironstone breccia, 3 feet thick	$0\frac{1}{2}$–3
No. 33.	Brown clay. At West Kachuku it is represented by a pale-buff-coloured sandstone, with lenticles of travertinous gravel	$3\frac{1}{2}$
No. 34.	Orange-coloured marlstone, with *Ampullaria ovata.* At West Kachuku it is represented by 6 feet of greenish-grey clay with numerous seams of travertine	$1\frac{1}{2}$
No. 35.	Brown clay	2
No. 36.	Brown sandstone. Nos. 33 to 36 are absent at South Nira and Nos. 35 & 36 are represented at West Kachuku by 5 feet of orange-brown marlstone with seams of travertine.	$0\frac{2}{3}$
No. 37.	Mottled crimson and pale-yellow clay, traversed by a vein of quartz. It is represented at West Kachuku, and even so far east as the cliff of East Kachuku. At East Kachuku Nos. 30 to 36 have thinned out, and at Kikongo Nos. 30 to 37 are completely missing	11

EXPLANATION OF PLATES XX–XXVI.

Plate XX.

Upper end of gully at Nira, looking north-east by east, showing the Upper Series. (See p. 130.)

Plate XXI.

Kachuku, upper end of gully, looking north-eastwards, showing part of the Upper and the Middle Series; the basaltic peak of Nundowat is seen in the distance. (See p. 131.)

Plate XXII.

Fig. 1. Gully of West Kachuku, looking north-north-westwards, showing the ledge of calcareous conglomerate (Bed 30); the basaltic hill of Nira is seen in the distance. (See p. 133.)

2. Lower part of Kachuku Gully, looking north-eastwards, showing the Upper Gravel Zone of Bed 31, containing *Dinotherium*, Anthracotheres, giant tortoise, etc.; the basaltic peak of Nundowat is seen in the distance. (See p. 133.)

Plate XXIII.

Fig. 1. Gorge of the Kuja, looking east-north-eastwards, showing the exit of the river from the Vinyo Escarpment. (See p. 149.)

2. Edge of the Manga Escarpment (quartzite), with the dolerite-sill at its base forming the fertile district of Kitutu. (See p. 151.)

Plate XXIV.

Crater-lake of Simbi, looking south-eastwards. (See p. 156.)

Plate XXV.

Geological map of the district between the Victoria Nyanza and the Kisii Highlands, on the scale of $4\frac{1}{2}$ miles to the inch, or 1 : 285,120.

Plate XXVI.

Fig. 1. Geological map of the neighbourhood of Karungu, showing the outcrop of the Miocene deposits at Nira, Kachuku, and Kikongo, on the scale of 2 miles to the inch, or 1 : 126,720.

2. Plan of the outcrop of the Miocene deposits at Nira, on the scale of 75 yards to the inch, or 1 : 2700.

3. Plan of the outcrop of the Miocene deposits at Kachuku, on the scale of 75 yards to the inch, or 1 : 2700.

F. O., Photo.

Bemrose, Collo., Derby.

Upper end of gully at Nira, looking north-east by east, showing the Upper Series.

KACHUKU, UPPER END OF GULLY, LOOKING NORTH-EASTWARDS, SHOWING PART OF UPPER AND MIDDLE SERIES; THE BASALT PEAK OF NUNDOWAT IS SEEN IN THE DISTANCE.

Fig. 1. Gully of West Kachuku, looking north-north-westwards.

F. O., Photo.

Fig. 2. Lower part of Kachuku Gully, looking north-eastwards.

F. O., Photo.

Bemrose, Collo. Derby.

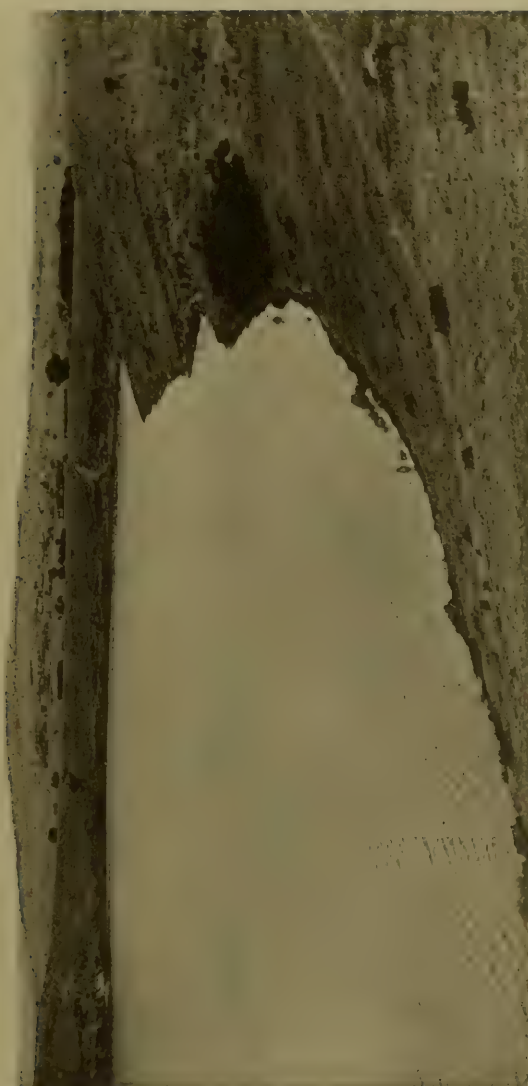
FIG. 1. GORGE OF THE KUJA, LOOKING EAST-NORTH-EASTWARDS.

F. O. Photo

FIG. 2. EDGE OF THE MANGA ESCARPMENT (QUARTZITE).

F. O. Photo.

Bemrose. Collo. Derby



F. O., Photo.

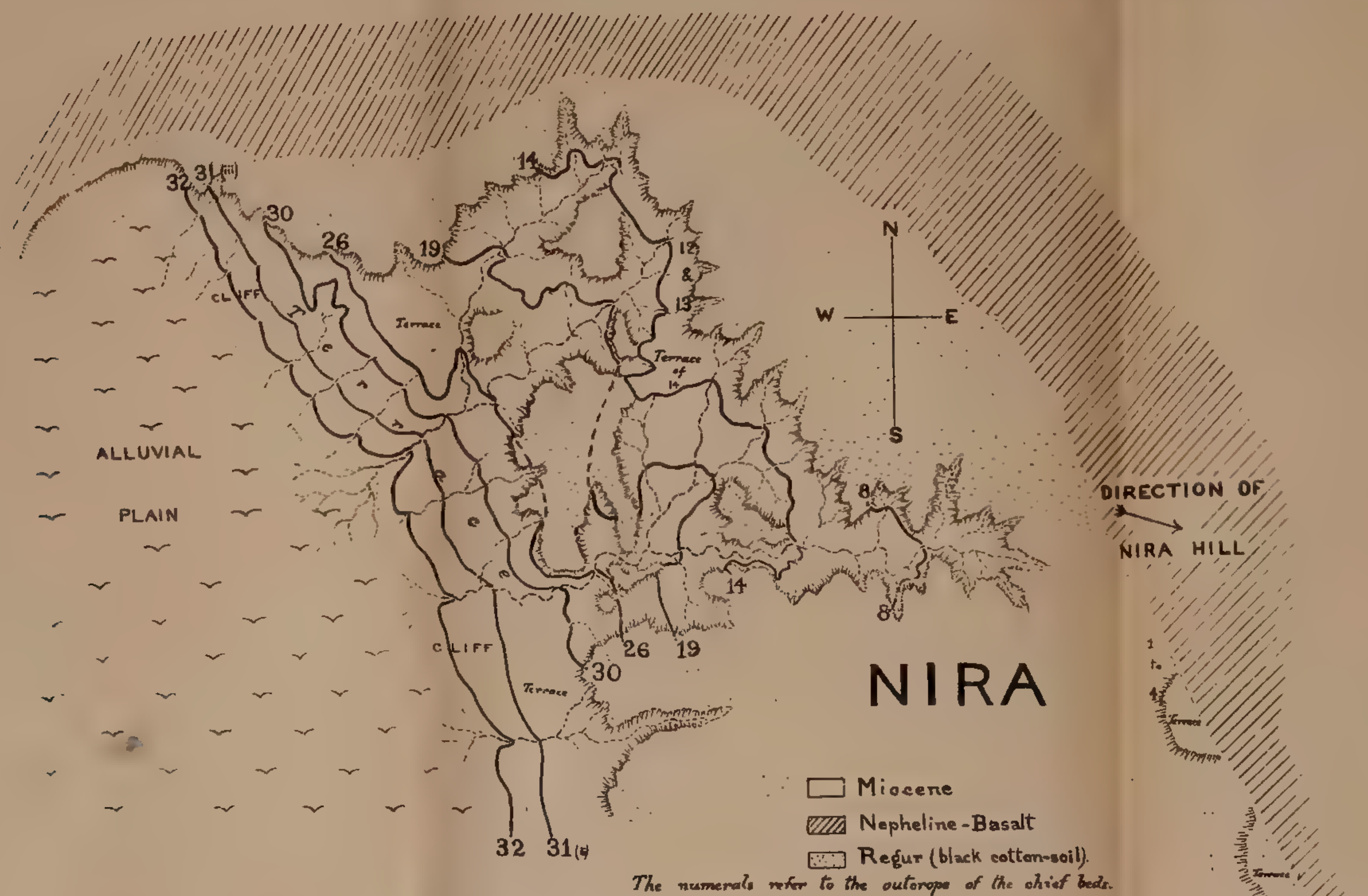
Bemrose, Collo., Derby.

Crater-Lake of Simbi, looking south-eastwards.


32° E KAMPALA
34° E
ENTEBBE
0°
KISUMU
BUDDU
VICTORIA
AREA OF MAP

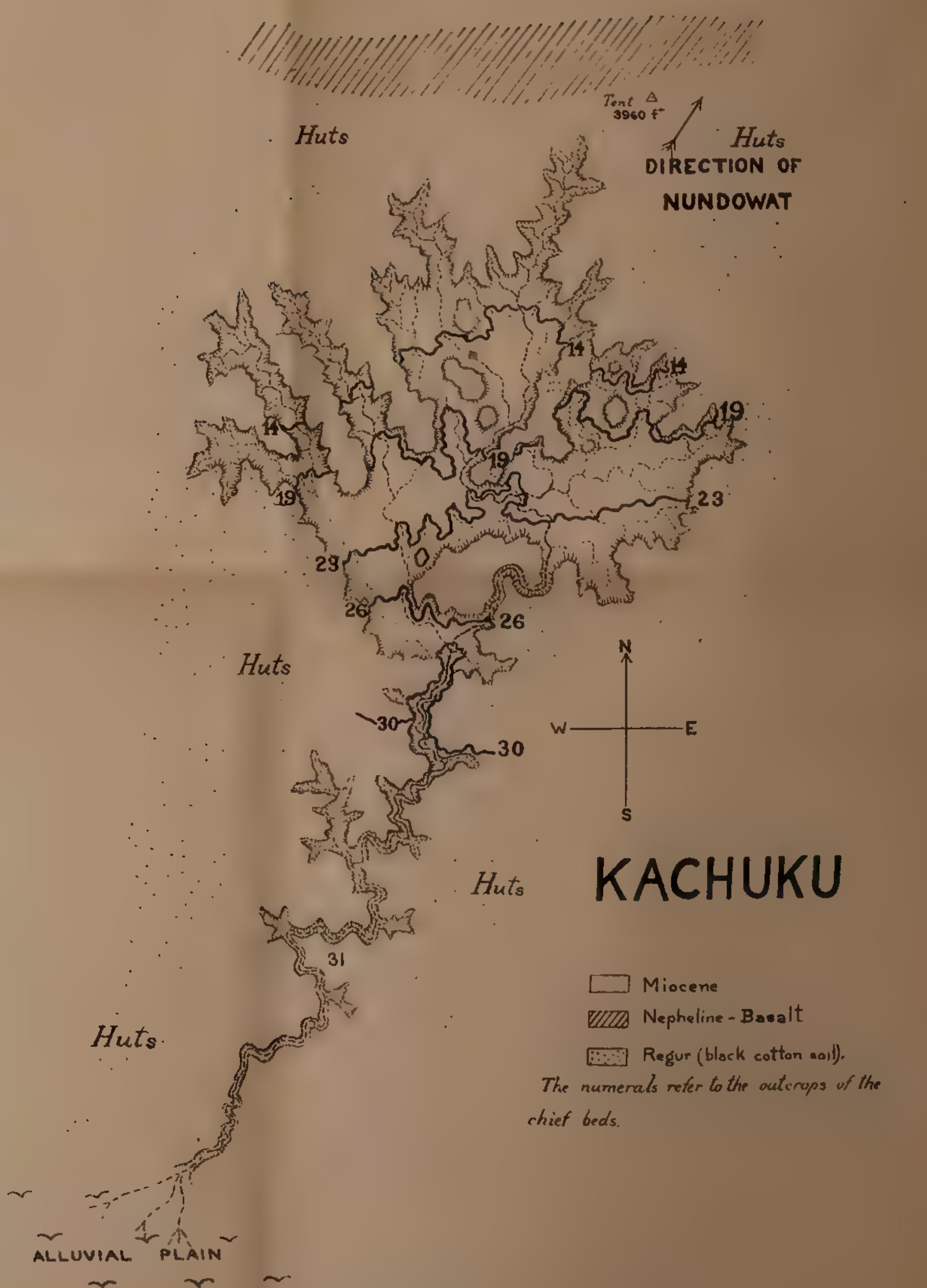

GEOLOGICAL MAP OF THE DISTRICT BETWEEN THE VICTORIA NYANZA AND THE KISII HIGHLANDS.
Pliocene of Homa
Miocene of Karungu
Quartzite of Kisii.
Schists of Wire, Vinyo, &c
Old quartz-porphyry
Karagwe Series
Later quartz-porphyry
Biotite gneiss
Hornblende-gneiss
Amphibolites & allied rocks weathering into Quartz-ironstone rocks
Dolerite
Augite andesite
Agglomerate & tuff of augite-andesite
Nepheline-basalt, phonolite, &c.
Alluvial deposits.
Author's route (the routes near Karungu are omitted for the sake of clearness)
Scale: 1 inch to 4½ miles, or 1: 285,120
KAVIRONDO GULF
HOMA BAY
3720 ft above the sea
Mbita Passage
RUSINGA
MFWANGANU
VICTORIA NYANZA
AREA OF MAP
NYANGO BAY
KISINGERE PLATEAU
USWANIA PLATEAU
BUE PLATEAU
KAMAGAMBO PLATEAU
Simbi Crater-lake
KISII HIGHLANDS
Kisii Boma
MIOCENE BEDS occur along this zone at NIRA, KACHUKU, KIKONGO and MINY ERE
Karungu
Utangi Plain
WACHURU HILLS
BINGU HILLS
ANGLO-GERMAN FRONTIER
F. OSWALD del.

Fig. 2. PLAN OF THE OUTCROP OF THE MIOCENE BEDS AT NIRA.



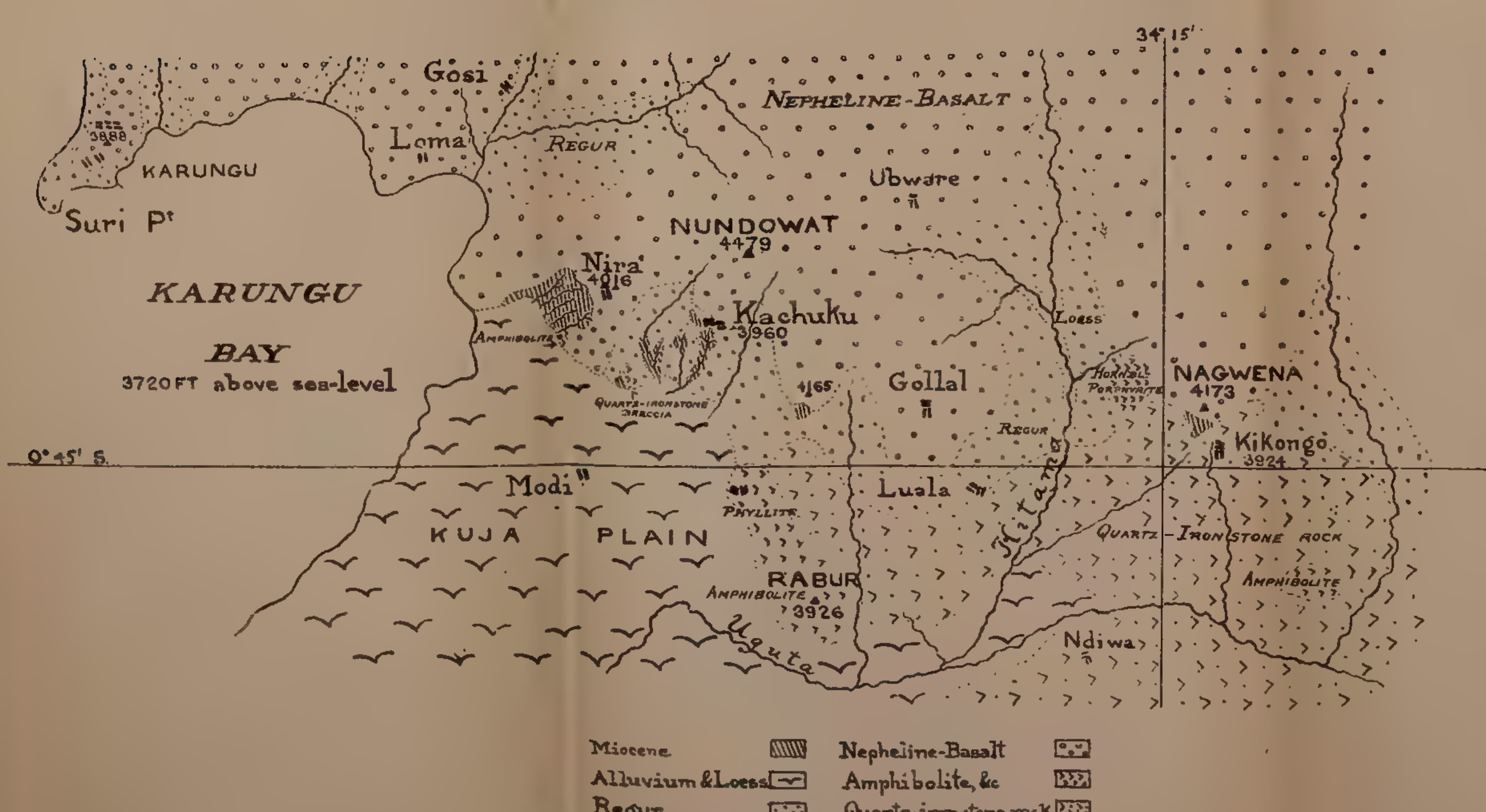
(Scale: 75 yards = 1 inch, or 1 : 2,700.)

Fig. 3. PLAN OF THE OUTCROP OF THE MIOCENE BEDS AT KACHUKU.



(Scale: 75 yards = 1 inch, or 1 : 2,700.)

Fig. 1. GEOLOGICAL MAP OF THE NEIGHBOURHOOD OF KARUNGU, SHOWING THE OUTCROP OF THE MIOCENE DEPOSITS AT NIRA, KACHUKU, AND KIKONGO.



(Scale: 2 miles = 1 inch, or 1:126,720.)

Appendix II.

On the Lower Miocene Vertebrates *from* British East Africa, *collected by* Dr. Felix Oswald.[1] *By* Charles William Andrews, D.Sc., F.R.S., F.G.S.

[Plates XXVII–XXIX.]

In this paper it is proposed to describe the vertebrate remains collected by Dr. Oswald from beds of Lower Miocene age in the neighbourhood of Karungu, near the eastern shore of the Victoria Nyanza. Some other specimens of late Pliocene or Pleistocene age will be described elsewhere.

The beds from which the Miocene vertebrates were collected appear to form part of the deposits of the delta of an old river, flowing into the lake at a time when its surface was considerably above its present level. These deposits are described in detail in Dr. Oswald's paper.

The mammalian fauna includes: Proboscidea, especially *Dinotherium hobleyi*, previously described[2] from the same locality; Artiodactyls, represented mainly by Anthracotheres; Perissodactyls, represented by a Rhinoceros; a small Hyracoid of peculiar character; a Rodent; and a feline Carnivore. The Reptilia are represented by Chelonians, including a new species of *Cycloderma*, a gigantic species of *Testudo* (also new), and a species of *Podocnemis*; by Crocodiles of several types, including probably a species of *Pristichampsa*, a genus previously known only from the Eocene of France. Fishes are represented by a few vertebræ and teeth, including one of a species of *Protopterus*.

The general character of the fauna indicates that the age of the deposits is probably Lower Miocene (Burdigalien) and that it was contemporary with the faunas of the Sables de l'Orléanais and of Moghara, and probably also with the recently-discovered[3] fauna of the Bugti Hills in British Baluchistan. In all these localities Anthracotheres of similar type appear as an important constituent of the fauna; and, although at present the characteristic small form of *Dinotherium* has not yet been found at Moghara, nevertheless a primitive *Tetrabelodon*, closely similar to *T. angustidens*, which elsewhere accompanies the *Dinotherium*, has been found in that locality. The occurrence of a peculiar form of Hyracoid in these beds might have been expected, when it is considered that in the Upper Eocene of Egypt the group was represented by a great variety of forms differing much in size and tooth-structure. Probably further researches will show that this once-important

[1] Communicated by permission of the Trustees of the British Museum.
[2] Proc. Zool. Soc. 1911, p. 943.
[3] G. E. Pilgrim, 'The Vertebrate Fauna of the Gaj Series in the Bugti Hills and the Punjab' Palæont. Ind. n. s. vol. iv, mem. 2 (1912); also C. Forster-Cooper in Ann. Mag. Nat. Hist. ser. 8, vol. viii (1911) p. 711.

group attained a high degree of differentiation before it declined to its present obscure position. The Rodent is perhaps a direct descendant of *Phiomys* of the Egyptian Upper Eocene. Of the Reptilia the most important is the giant species of *Testudo*, which is especially interesting as giving further proof of the wide distribution of these creatures on continental areas in Tertiary times. The fact that these reptiles in recent times are found only on islands may be simply explained by supposing that they are survivals of formerly more widespread groups, and have escaped extinction owing to a relative absence of enemies and of competition under insular conditions.

It is unfortunate that in the collection now described most of the species are represented by mere fragments; nevertheless, they are sufficient to show that future investigations among the Tertiary deposits of this region will yield most valuable results.

PROBOSCIDEA.

The most important specimen referable to a member of this group is an imperfect right ramus of the mandible of *Dinotherium hobleyi* Andrews, the symphysial and posterior portions of which have been broken away; the cheek-teeth (pm_4–m_3) are beautifully preserved. This mandible is rather smaller than that upon which the species is founded,[1] and is more complete; in the type-specimen m_1 was wanting.

Anteriorly the jaw is broken across immediately in front of the point where it begins to curve inwards and downwards towards the deflected symphysis characteristic of the genus, the deflection commencing at about the level of the posterior ridge of pm_4. Behind this, as far as the posterior end of m_2, the inner face of the jaw is nearly flat. Behind this, again, the upper half of the inner face curves gently outwards towards the posterior expansion, while the lower half is concave from above downwards. The ventral border of the ramus is nearly straight until some 4 or 5 centimetres behind the dental series, where it is interrupted by a roughened tuberosity, projecting a little outwards and downwards, and separated from the angular region by a well-marked notch; the greater part of the angular region is wanting.

The outer face of the ramus beneath pm_4 and m_1 is slightly concave from above downwards, but below and behind this it becomes strongly convex in that direction, passing below by a wide curve into the inner face. The mental foramen is situated rather more than half way down the outer face of the jaw beneath pm_4. The anterior edge of the ascending ramus is situated about opposite the second ridge of m_3, and it arises some distance below the alveolar border, from which it is separated by a broad concave surface. A strong ridge, continuous at its lower end with the inner edge of the alveolar surface, runs upwards and forwards on to the inner face of

[1] Proc. Zool. Soc. 1911, p. 943.

the ascending ramus, the surface of which behind this ridge is much roughened for the attachment of muscles. The lower part of this ridge forms the hinder border of the alveolar surface: that surface extends some distance behind the last molar, and is perforated at its posterior angle by a small foramen. The outer face of the ascending ramus is nearly flat; unfortunately, both the coronoid process and the condyle are wanting. This mandibular ramus is similar to that of *Dinotherium cuvieri*, which, however, is rather larger and stouter, the outer face of the ramus being more convex.

The teeth preserved in this specimen are pm_4–m_3. The premolar and the last two molars have already been described in detail in the account[1] of the type jaw; the only differences in the present specimen, apart from its rather smaller size, are that the anterior lobe of the premolar is smaller and the talon of m_3 more rounded and its inner edge crenulated; there is also a more distinct trace of a cingulum on its hinder face.

The first molar (Pl. XXVIII, fig. 1), as usual in the genus, consists of three transverse ridges, the posterior one being much the smallest. There is a slight trace of a cingulum at the outer end of the anterior valley, and also on the posterior face of the third ridge; on the inner side the cingulum is absent. In *Dinotherium cuvieri* the cingulum is better developed at the outer end of the anterior valley, and it is also present on the outer side of the first ridge.

The dimensions (in centimetres) of this specimen are:—

Length in a straight line (so far as preserved)	38·8
Depth of ramus beneath m_2	10·5
Length of molar-premolar series (pm_3–m_3)	24·3

The dimensions of the teeth (in centimetres) are:—

	Length.	*Width.*
pm_4	4·6	4·0
m_1	5·6	4·0
m_2	5·8	5·2
m_3	6·5	5·3

A right upper premolar (Pl. XXVIII, fig. 2) in the collection is nearly quadrate in outline, the width being a little greater than the length. The crown is composed of two transverse crests, which are highest at their outer and inner ends, being more obviously formed by the union of an outer and an inner cusp than is the case in the lower molars. The two outer cusps show some tendency to unite one with the other, the outer end of the transverse valley being much shallower than the inner, so that in an advanced state of wear the surfaces of the two cusps would become continuous. The cingulum is well developed on both the anterior and the posterior faces of the tooth; it is also present at the inner end of the transverse valley and as faint irregular tubercles on the outer face. There were three roots to this tooth, one at the antero-external angle, a second occupying the anterior portion of the inner side;

[1] Proc. Zool. Soc. 1911, p. 943.

while the third occupies the whole width of the posterior side of the tooth, and extends a little along the outer border.

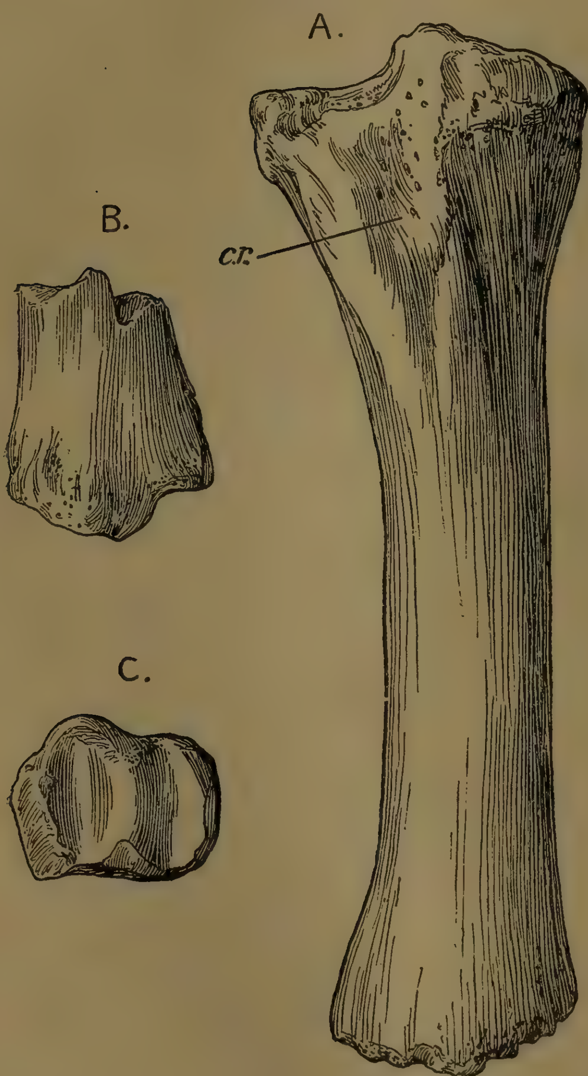
The dimensions (in centimetres) of this specimen are :—

Length	4·9
Width	5·4

Numerous fragments of the lower tusk of *Dinotherium* were collected ; these show no traces of the 'engine-turning' characteristic of the ivory of the upper tusks of *Elephas*, but indicate that the dentine was composed of concentric lamellæ, which tend to split apart as disintegration takes place. No trace of enamel has been observed on any of the fragments. One specimen of the tip of the tusk shows that it was strongly compressed at the end, which forms a sharp point.

The above-described specimens are from Bed 31.

Fig. 1.



A=Tibia of a Tetrabelodont seen from the front.
B=Distal end of a tibia of a large Anthracothere seen from the front.
C=The same, distal articular surface.
c.r.=cnemial crest.
[All the figures are a fifth of the natural size.]

In Bed 22, a Proboscidean tibia (fig. 1, A) was collected, the bone being well preserved and complete, except that the distal epiphysis is missing. It is very similar in structure to the tibia of an African elephant, with which it was compared, differing only in some minor features. Thus the pit for the insertion of the extensor muscles on the upper face of the cnemial crest is much less strongly marked on the fossil; while, on the other hand, the rugose surface below and at the side of it is more prominent. There is a deep

fossa immediately in front of the surface for the outer condyle of the femur, not seen in the recent tibia. The posterior face of the upper end of the shaft is deeply concave, as in the African elephant; but about the middle of the outer rim of the concavity there is a rugose surface, wanting in that species. The inner face of the upper end of the shaft is, moreover, flatter, and bears a deep roughened pit for muscle-attachment. Only one tibia of *Ele^has africanus* was available for comparison, so it is quite possible that some of the above-noticed differences may be merely individual variations.

If the tibia ascribed by Gaudry to *Dinotherium* really belongs to that animal, as there seems no reason to doubt, then the tibia now under discussion must belong to some other Proboscidean, the lower end of the shaft showing none of the antero-posterior compression seen in Gaudry's specimen. It is possible, therefore, that this specimen may indicate the presence in these deposits of a species, probably a Tetrabelodont, at present otherwise unknown.

The dimensions (in centimetres) of this specimen are:—

Length without distal epiphysis	54·6
Width of the proximal articular surface	17·5
Width of the shaft at its narrowest	8·6

Another portion of a much bigger tibia was collected in Bed 31. This seems to indicate the presence of an animal considerably larger than *Dinotherium hobleyi*, the fragment agreeing roughly in size with the corresponding bone of an African elephant standing about 8 feet at the shoulder. The inner side of the astragalar surface is incomplete, but what remains shows that the form of the astragalus was the same as that of the astragalus of *Dinotherium* described below—its tibial surface being gently convex from before backwards, but with no median depression from side to side, a point which distinguishes it from the astragalus of *Tetrabelodon*. The fibular surface is preserved; its line of union with the astragalar surface is not directly antero-posterior as in *Elephas*, but is directed somewhat inwards and backwards—in this the bone agrees with the tibia of *Dinotherium* figured by Gaudry. The fibular facet is relatively smaller than in *Elephas*; it is triangular in outline, and looks downwards and outwards, making a more obtuse angle with the fibular surface than in *Elephas*. On the whole, there does not seem to be much doubt that this bone belongs to a species of *Dinotherium* rather bigger than *D. hobleyi*.

A left astragalus of a Proboscidean was collected from Bed 31 at Nira. This specimen is much abraded, especially about its anterior and posterior borders, and consequently the exact form of the articular surfaces cannot be determined. The tibial surface is comparatively narrow from before backwards, and is gently convex in the same direction; it is not concave from side to side, and in this respect is distinguished from the astragalus of *Tetrabelodon angustidens*, which might be expected to occur in these beds. This absence

of any concavity from side to side is also observed in the astragalus of *Palæomastodon* and in a cast of an astragalus referred to *Dinotherium* by the late Prof. A. Fritsch. At its outer side the tibial surface passes by an obtuse angle into the convex facet for the fibula; internally it is obliquely truncated by a deeply-concave surface, apparently for the reception of a large internal malleolus of the tibia: a similar, but a relatively still larger, depression occurs in the astragalus of *Palæomastodon*. In the astragalus of Fritsch's *Dinotherium* the postero-internal angle of the bone, behind the depression, is produced into a prominent knob, which may or may not have been present in the specimen here described. The navicular surface is separated from the tibial by a very short neck, concave from above downwards. The surface itself is rhomboidal in outline, and gently convex. The exact form of the ectal and sustentacular facets for the calcaneum cannot be made out, owing to the abrasion of their edges; it can be seen, however, that the sustentacular facet is separated from that for the naviculare by a narrow groove, while in *Palæomastodon* and *Tetrabelodon* the two meet in an angle. The two calcaneal facets are separated one from the other anteriorly by a broad deep groove, which narrows towards its hinder end, where the two surfaces probably meet; they are flat or gently convex. In an incomplete calcaneum referred to *Dinotherium*, the corresponding surfaces agree in outline with those of the astragalus just described; but the sustentacular facet is gently convex, so that it would not fit against the corresponding astragalar facet—this may be due, however, to partial abrasion, or to an individual peculiarity.

The astragalus here described agrees very well with the cast of the astragalus referred to *Dinotherium* by Fritsch, and with the astragalus from Pikermi, described and figured by Gaudry [1] as that of *Dinotherium*, and there is little doubt that it belongs to *D. hobleyi*. The dimensions (in centimetres) of this specimen are:—

Greatest length	8·6
Greatest width	11·0
Width of the tibial surface (approximate)	7·7

A distal portion of a metapodial bone from Bed 20 at Kachuku indicates the presence of a Proboscidean much bigger than *D. hobleyi*. It is 6·7 centimetres wide at its distal articulation. The shaft is nearly quadrate in section, but the flat anterior face is rather wider than the posterior. The distal trochlear surface is somewhat abraded; it formed rather more than a semicircle. On one side is a deep pit for the attachment of ligament. This specimen agrees very closely with the third right metacarpal of a species of *Elephas* or *Stegodon* from the Siwalik Beds. It appears to be much too large to have belonged to *D. hobleyi*.

[1] 'Animaux fossiles & Géologie de l'Attique' 1862, p. 169 & pl. xxv, fig. 6.

HYRACOIDEA.

One of the most interesting of the specimens found is a fragment of the left ramus of the mandible (Pl. XXVIII, figs. 4 *a* & 4 *b*) of a small mammal about as big as a large rat. This is from Bed 16 at Kachuku. At first sight the jaw appears to be that of a Rodent, the great hypsodonty of the molars lending support to this view; but further examination shows that it cannot possibly belong to a member of that order, on account of the form and arrangement of the premolars. The jaw itself is gently convex from above downwards externally, and nearly flat internally; it is broken off immediately behind the symphysial region in front, and probably about the middle of the molar series behind—from before back wards it deepens with a gentle curve.

Four teeth are still *in situ*; in front of these are the two roots of another tooth, and anterior to this again an imperfect alveolus all these teeth formed a closed linear series. Anterior to and below this is the base of a larger tooth, the section of which is an elongated oval with the long diameter transverse; it appears to have been directed forwards and upwards, as if it were the root of a large procumbent incisor. Beneath it is a cavity which may represent the alveolus of another tooth, but this is very doubtful.

The first of the teeth preserved is doubtless a premolar (Pl. XXVIII, fig. 4 *b*, pm_3); its crown is composed of two elongated **U**-shaped lobes, separated externally by a short deep groove, which does not extend to the base of the crown. On the inner face the lobes are not so clearly separated, the face being nearly flat in consequence of wear. The anterior lobe is the bigger, and is borne on a large root; while the smaller posterior lobe has a much smaller root. The enamel is quite smooth, and is thickest on the outer face of the tooth; there is no trace of a cingulum. The tooth in front was smaller, but doubtless otherwise similar, the roots showing exactly the same arrangement.

The crown of the next tooth preserved is also composed of two elongated lobes, somewhat **V**-shaped on the outer face, the anterior arm of the **V** being much the longer. Externally, the lobes are separated by a deep vertical groove extending nearly to the base of the crown, which is here becoming very high and prismatic in form; the tooth, as a whole, is slightly curved, with the convexity directed forward. On the inner face the columns are likewise separated by a vertical groove: the anterior column is the longer from before backwards; its postero-internal edge forms a prominent ridge (metaconid) on the inner side of the tooth, constituting the anterior lip of the vertical groove already mentioned.

The next tooth is still more hypsodont, and the columns are stouter and broader, their crescentic form being less distinctly shown. The same is also true of the next tooth, in which the hypsodonty reaches its highest pitch, so that there is considerable resemblance to some Rodent molars. Despite the hypsodonty,

the roots of the molars are well formed, and clearly separated from the crown; they are closed at the ends, except for the entrance of the nerve. They are two in number, each extending transversely across the tooth. The crown of the tooth is entirely covered by enamel, which in the anterior premolars is smooth, but in the hypsodont teeth is raised into faint irregular ridges at right angles to the long axis of the tooth. On the crown the dentine is worn into deep hollows surrounded by enamel, highest at the outer side and at the angle formed by the metaconid.

The determination of the position in the series of the above-described teeth is difficult, since it is uncertain whether there was not at least one other tooth behind those preserved. This is rendered the more probable, because the collection includes an isolated tooth which shows traces of a posterior third lobe (Pl. XXVIII, figs. 5 & 5 *a*), and would therefore probably be the last lower molar. If this be the only molar missing from the jaw, then the teeth preserved would be pm_3, pm_4, m_1, m_2, while the roots and alveoli in front would indicate the presence of pm_1, pm_2, the whole of the premolars and molars forming a continuous series. This interpretation is further supported by the circumstance that the tooth here regarded as m_1 is much more worn than the tooth in front (pm_4). If this view of the nature of the teeth be correct, then it is clear that the increasing hypsodonty had already affected the last premolar. The incisor is represented by its root only; it was procumbent, and transversely elongate in section. It is not clear whether a second pair of incisors was present, nor can the existence of a canine be made out.

The affinities of this small mammal are difficult to determine; but it seems most likely that it is a very small Hyracoid, in which the molars have become extremely hypsodont. The chief reason for this interpretation is founded on the number and, judging from pm_4, on the form of the premolars, which are very similar to those in the young *Hyrax* and perhaps still more to those in *Saghatherium*. Again, the form of the tooth-crown in the molars is very similar to that observed in much-worn molars of the more hypsodont species of *Hyrax*.

The occurrence of an upper molar (Pl. XXVIII, figs. 6 *a* & 6 *b*), probably belonging to the same species, supports the view that I have taken as to its Hyracoid affinities. This tooth is a very hypsodont prismatic molar, which shows a wear pattern that might be easily derived from a Hyracoid molar. The ectoloph consists of a well-developed parastyle, an antero-external cusp (paracone) and a postero-external cusp (metacone), all of which form prominent vertical ridges on the outer face; there does not appear to be any mesostyle. The inner part of the tooth is composed of two transverse crests (protoloph and metaloph), the inner end of the protoloph being somewhat imperfect. Each crest seems to be made up of a smaller middle tubercle (protoconule and metaconule respectively) and a larger inner tubercle (protocone and hypocone respectively); these are separated on the inner face of the tooth by a deep vertical cleft. In wear, two islands of cement

surrounded by enamel are formed in each crest, the larger outer islands being crescentic and situated immediately internal to the paracone and metacone respectively. The smaller islands are situated just external to the protocone and hypocone; in wear, the latter tubercle becomes continuous with the posterior wall of the tooth. The anterior and posterior faces of the tooth are flat, with a band of cement near the outer edge; the inner face is slightly concave from above downwards, the outer correspondingly convex. There is a slight increase of size in the tooth towards the roots, of which there seem to have been four.

The dimensions (in millimetres) of these specimens are:—

Mandible:	
Length of the grinding-surface of the four teeth	12
Length of the specimen as a whole	17

Lower teeth:	*Length.*	*Width.*	*Height of crown (outer side).*
? pm 3	1·7	1·1	1·8
(?) pm 4	3·1	1·3	3·0
(?) m 1	3·5	1·8	5·0
(?) m 2	3·1	2·0	6·0
Upper molar	4·0	3·0	5·0

If this animal is rightly regarded as a Hyracoid, it differs from the other members of the group in (1) its very small size, and (2) the extreme hypsodonty of its molar teeth. I propose to refer this species to a new genus, *Myohyrax*, under the specific name *M. oswaldi*. It must also be regarded as the representative of a new family, the Myohyracidæ. The fact that in the Upper Eocene (Oligocene of most authors) of Egypt the Hyracoidea were already represented by a great variety of forms with widely differing types of dentition, shows that they were a group of great importance and plasticity, and so there is nothing remarkable in finding a type such as is here described in beds of Lower Miocene age. Probably, when the early Tertiary faunas of Africa are better known, many other striking modfiications of the same group will be found.

ARTIODACTYLA.

Family ANTHRACOTHERIIDÆ.

This group is represented by portions of the skeleton of at least two species of Anthracotheres. The specimens include a fragment of a mandible with m_3 *in situ*, humeri, portions of tibiæ, carpals, and tarsals.

The fragment of mandible (Pl. XXIX, figs. 3 *a* & 3 *b*) from Bed 31 consists of the hinder portion of the left ramus with the last molar complete, except for the loss of the postero-internal cusp, and the roots of the second molar. The molar is a comparatively hypsodont tooth, approximating in this respect to the molar of *Ancodon*. The inner cusps are particularly high and sharp-pointed; the outer

cusps are **V**-shaped, and the anterior limb of the **V** is strongly developed, that of the antero-external (protoconid) cusp extending to the antero-internal angle of the tooth and entirely cutting off the antero-internal cusp (metaconid) from the anterior border of the tooth. Similarly, the anterior limb of the postero-external cusp (hypoconid) extends quite to the inner border of the tooth, separating the metaconid from the entoconid and blocking the inner end of the transverse valley. The talon is a narrow loop, the outer wall of which is much the highest; posteriorly it terminates in a high sharp cusp. A cingulum is present on the anterior end of the tooth, and at the outer end of the posterior transverse valley. The enamel is sculptured by a series of fine irregular ridges running towards the tips of the cusps. The depth of the mandibular ramus seems to have been greater than in *Ancodon*, in this respect approximating to *Brachyodus*.

In the height of its cusps the tooth above described approaches those of some species of *Ancodon*, such as *A. velaunus* (Cuvier); but it is distinguished from that genus by the strong development of the anterior limb of the outer cusps and by their relations to the inner cusps. In this respect it appears to resemble *Merycops*, at least so far as it is possible to judge from Mr. Pilgrim's description—the figures given by him are indistinct. There is also considerable similarity with the corresponding teeth of *Merycopotamus* and *Hemimeryx*; for the present, this species may be called *Merycops africanus*, sp. nov., but further material is necessary for its complete determination.

The dimensions (in centimetres) of this specimen are:—

Length of specimen	6·7
Depth of ramus beneath the middle of m_3 ...	3·1
Length of m_3	3·1
Width of m_3	1·5

Another tooth (Pl. XXIX, figs. 4 *a* & 4 *b*) probably belonging to a member of this group is a right lower canine tusk. This tooth, as a whole, is strongly curved, forming an arc of a circle. The crown, which is short, is sharp-pointed and triangular in section, the outer somewhat convex face being the widest. The posterior side is formed by a flat surface of wear, which on the inner side extends down to the cement-covered root. The enamel is covered with a series of fine irregular wrinkles, directed towards the summit of the crown and most clearly marked on the inner face. The large cement-covered root is roughly triangular in section, and is scored along its length by a series of shallow grooves, one situated towards the outer side of the inner face being much the most strongly developed. This tooth, except for the shortness of its crown, is remarkably similar to the canine of a small *Hippopotamus*. It seems probable that, like the molar above described, it belonged to an animal resembling *Merycopotamus* and perhaps ancestral to *Hippopotamus*, which was almost certainly derived from an Anthracotheroid type.

The dimensions (in centimetres) of this tooth are :—

Length in a straight line	9·5
Length along outside of curve (approximate) ...	13·2
Width of middle of root	2·5

The Anthracotheres are also represented by several limb-bones, including humeri, a femur, part of a tibia, carpals, and tarsals. Some of these must have belonged to animals considerably bigger than those to which the teeth above described belonged, and indicate that several members of the group lived in this region in Lower Miocene times.

A very well-preserved humerus (fig. 2, p. 174) of large size probably belongs to a member of this group, and must represent a much bigger animal than those to which the teeth described above belong. In a general way, it is similar to the humerus of *Brachyodus rugulosus* described and figured by Dr. Martin Schmidt,[1] but differs in many details. The articular surface of the head (fig. 2, B, *h.*) is roughly triangular in outline, one angle projecting posteriorly to a considerable extent; it is strongly convex from before backwards, and less markedly so from side to side—anteriorly it is separated from the base of the tuberosities by a basin-like hollow. The outer tuberosity (fig. 2, *o.t.*) is massive, and to some extent overhangs the bicipital groove (*b.g.*), which does not appear to be the case in *Br. rugulosus*; on the other hand, it rises very little above the articular surface as in that species, thus differing from the greater tuberosity of *Ancodus* as described by Prof. W. B. Scott.[2] In *Hippopotamus* also the tuberosity rises high above the head of the humerus. The inner tuberosity (*i.t.*) is massive, and its anterior surface, forming the hinder wall of the bicipital groove, bears a broad convex ridge, which divides the groove into a larger anterior and a smaller posterior portion.

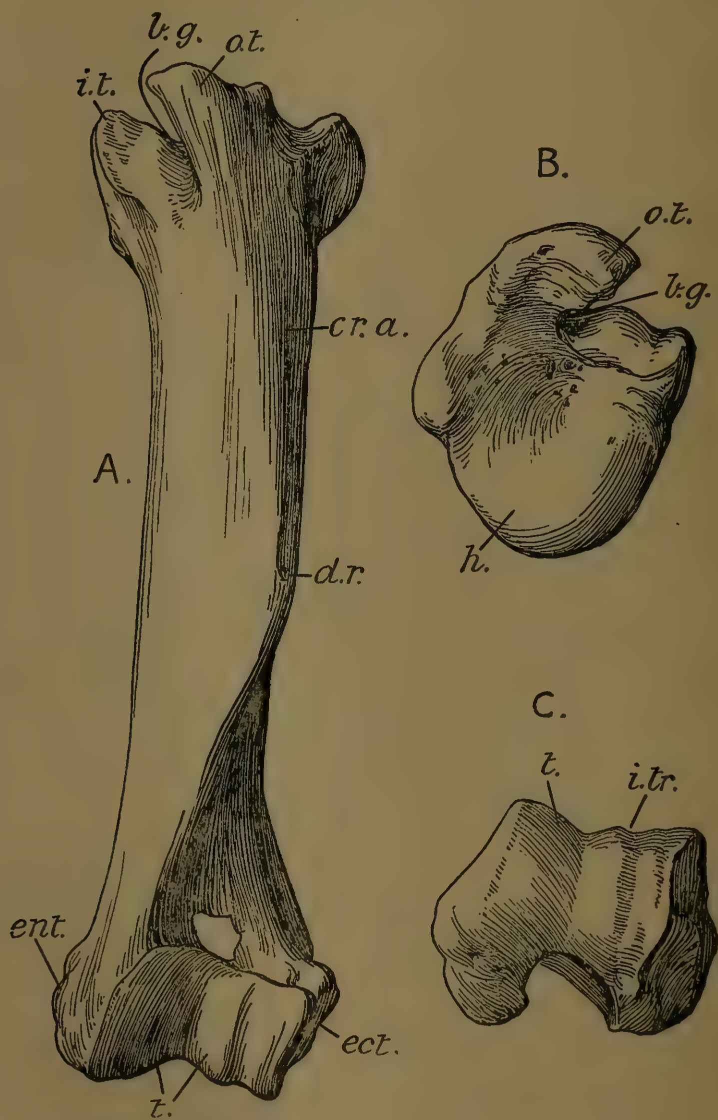
The shaft of the bone is straight, relatively slender, and somewhat compressed laterally. The crista anterior (*cr.a.*, fig. 2, A) running down from the outer tuberosity is not well marked; but the deltoid ridge (*d.r.*, fig. 2, A) forms a strong anterior prominence situated about the middle of the bone, and in its upper portion hollowed by a roughened concavity. At the distal end there seems to have been a supratrochlear foramen; this is, however, not quite certain, the very thin wall of bone between the olecranon and the supratrochlear fossæ having perhaps been broken away by accident. The trochlear surfaces (*t.*, fig. 2, A & C) are oblique; the intertrochlear ridge (*i.tr.*) is highly developed, and situated well to the outer side of the trochlear groove, so that the outer surface for the radius is considerably narrower than the inner, much as in

[1] 'Ueber Paarhufer der Fluviomarinen Schichten des Fajum' Geol. Paläont. Abhandl. Jena, vol. xv (1913) p. 200 [48] & pl. xxi [v], figs. 1–3, 11.

[2] 'The Structure & Relationships of *Ancodus*' Journ. Acad. Nat. Sci. Philad. ser. 2, vol. ix (1895) p. 474.

Brachyodus. In *Diplopus* the intertrochlear ridge is less marked, and nearer the middle of the surface; moreover, the outer border of the articulation is strongly produced downwards, a condition

Fig. 2.—*Humerus of an Anthracothere (a fifth of the natural size).*



A, seen from the front. B = Proximal end. C = Distal end.

b.g., bicipital groove; *cr.a.*, crista anterior; *d.r.*, deltoid ridge; *ect.*, ectocondyle; *ent.*, entocondyle; *h.*, head; *i.t.*, inner tuberosity; *i.tr.*, intertrochlear ridge; *o.t.*, outer tuberosity; *t.*, trochlear surface.

not seen in the specimen now described. The entocondyle (*ent.*, fig. 2, A) is large, and bears on its outer side a large tuberosity for the attachment of muscles; its posterior angle does not project

beyond the articulation and is rounded off, not forming a right angle as in *Brachyodus*. The ectocondyle (*ect.*, fig. 2, A) is prominent, but the supinator ridge is not well marked. On the whole, this bone may be regarded as belonging to a large Anthracothere, probably allied closely to *Brachyodus*.

A second less perfect humerus (specimen *b*), of smaller size, though otherwise similar, was collected; and from beds of the same age at Moghara I obtained another similar but still smaller humerus. Probably, therefore, the fauna of this horizon in Africa will be found to include a great variety of Anthracotheroid Ungulates, differing much one from the other in size and in other respects, just as is the case with the contemporary fauna of the Bugti Hills in British Baluchistan.

The dimensions (in centimetres) of these specimens are:—

	Specimen *a*.	Specimen *b*.
Length	53·0	43·9 (approx.)
Greatest antero-posterior width of proximal end	18·2	—
Greatest antero-posterior width of articular surface	11·0	10·0
Antero-posterior diameter of middle of shaft.	9·1	—
Lateral diameter of middle of shaft	6·5	—
Greatest width of distal end	13·6	11·4
Width of distal articular surface	8·5	7·3

A very imperfect femur of an animal, at least as big as that to which the largest of the above humeri belonged, probably should be included here. It is imperfect at both ends; but it can be seen that the great trochanter was very large, with a deep digital fossa. The shaft was oval in section, its long diameter measuring about 8·5 centimetres; its posterior face bears a very strongly-marked *linea aspera*. The distal end is too imperfect for description.

A distal end of a right tibia (fig. 1, B & C, p. 166) indicates the existence of an Anthracothere still bigger than that to which the larger humerus above described belonged. The distal articulation is typically Artiodactyl in form; but the internal malleolus is broken away, and the rim of the articular surface is incomplete in some places. The two concave surfaces for the reception of the astragalus are approximately equal in size; on the inner border of the inner astragalar surface, opposite the anterior end of the internal malleolus, the surface is notched by a well-marked pit—this is also obscurely indicated in a very closely similar tibia from Moghara, but is not seen in *Diplopus*, *Brachyodus gorringei*, or *Sus*. On the other hand, in the tibia of *Hippopotamus* there is a large notch with a deep fossa at this point. This comparatively unimportant character, like the absence of the notch in the acetabulum of *Brachyodus*, may point to the close relationship of these African Anthracotheres with *Hippopotamus*. The outer angle of the distal end of the bone is truncated by a roughly-triangular

rugose surface for the fibula. Of the shaft a length of only 10 to 12 centimetres is preserved; its anterior face is nearly flat, while its sides and posterior face form a continuous convexity from side to side. The dimensions (in centimetres) of this tibia are:—

Width of distal articulation from side to side	10·0
Width of the same from front to back	8·0
Width of shaft, 10 centimetres above the articulation	7·2

Members of this sub-order are also represented in the collection by fragmentary remains, which indicate the existence of several distinct forms, but are too scanty to permit of definite determinations being made. The Tragulidæ are probably represented by two or three species. Thus, an upper much-worn molar is closely similar to one of *Prodremotherium*, and to this form also may perhaps be referred the distal end of a humerus and some small astragali. A lower molar of a somewhat larger animal from Bed 15 at South Nira is very like the same tooth of *Dorcatherium nani* Kaup, and to this an astragalus may also be referred. There is, moreover, the distal end of a tibia, which does not seem to agree with either of these types. Finally, a well-preserved right astragalus from Bed 13 at Nira appears to belong to an antelope-like animal about the size of a large goat, and an imperfect calcaneum may be referred to the same form.

On the whole, the collection indicates that in the Lower Miocene, as at present, the Artiodactyla formed the most important constituent of the African fauna.

Sub-order PERISSODACTYLA.

This sub-order is represented by some scanty remains of a Rhinoceros. The chief specimens are a third right upper molar (Pl. XXVIII, fig. 3), portions of the radius, and some odd foot-bones.

The molar is well preserved, and seems to have been freshly broken from the jaw. The form of the rather hypsodont crown will be best understood from the figure. It will be seen that it was triangular in outline, with a strongly-developed cingulum on the inner part of the anterior face; there is also a slightly-developed ridge of the cingulum at the inner end of the transverse valley. On the postero-internal angle near the base of the crown is a small prominence, which Prof. O. Abel regards as representing the hinder end of the ectoloph; if this be so, however, not only is the metaloph very greatly reduced, but the crochet arises from the ectoloph—it seems probable that, in this case at least, the prominence belongs to the cingulum. The crochet is small, and there are distinct traces of the crista. Comparison with the corresponding tooth of several species of *Rhinoceros* shows that the specimen here described most nearly resembles m_3 of *Rh. schleiermacheri*, but is somewhat larger and differs in the presence of the cingulum at the inner end of the

valley, a structure not seen in the specimens examined. Prof. H. F. Osborn [1] considers that the sub-family—the Ceratorhinæ—to which *Rhinoceros schleiermacheri* belongs first appears in the Middle Miocene of Europe, where it is represented by *Rh. sansaniensis*. Dr. L. Mayet,[2] on the other hand, carries the line back to *Rh. tagicus* Roman, from the Burdigalian Beds of Portugal. If further discoveries confirm the relationship of the species here described with *Rh. schleiermacheri*, it would seem that a probably African origin may be assigned to the Ceratorhinæ, but much more material is necessary before any conclusion can be drawn.

The dimensions (in centimetres) of this tooth are:—

Greatest width of the crown at the base	6·5
Greatest length of the crown	5·6

A portion of the upper part of the radius shows that it was not fused with the ulna, and that the limb was probably not very heavy. A left os magnum and a left cuboid are also included in the collection.

Order RODENTIA.

This order is represented by a fragment of the left ramus of the mandible (Pl. XXVIII, fig. 7) of an animal almost as big as a guinea-pig; the fourth premolar and the first and second molars are *in situ*. This specimen is from Bed 24 at Kachuku.

The teeth are brachyodont, and each molar consists of two outer heart-shaped cusps (protoconid and hypoconid), the external angles of which are directed forwards—the two being separated by a deep groove directed somewhat backwards. The inner face of the tooth bears two cusps, the metaconid and the entoconid : of these the former is connected with the protoconid by a ridge which forms the anterior wall of the tooth-crown. The entoconid is connected by a ridge crossing the middle of the crown to the inner point of union of the wear-surfaces of the antero-external and postero-external cusps. At the bottom of the bay between this transverse ridge and the anterior wall of the tooth is a slight prominence, apparently the rudiment of another transverse ridge. Finally, the postero-external cusp is connected with a ridge forming the hinder wall of the crown (hypoloph); this turns strongly forwards at its inner end, and in wear would become connected with the postero-internal cusp (entoconid), enclosing an enamel-covered valley. The enamel on the outer side of the external cusps is very thick, but the internal cusps are the most prominent.

The premolar, so far as its posterior half is concerned, is similar to the same part of the molar; but the anterior region is reduced, and appears to consist of one large cusp or (perhaps, more properly)

[1] Bull. Am. Mus. Nat. Hist. vol. xiii (1900) p. 256.

[2] 'Étude des Mammifères Miocènes des Sables de l'Orléanais' Ann. Univ. Lyon, n. s. Sciences, fasc. xxiv (1908) p. 113.

two closely-united cusps, the outer of which is united with the postero-external cusp, while the inner is separated from the middle transverse crest by a well-defined valley extending half way across the crown.

These teeth seem to be very similar to the lower teeth of *Phiomys* described by Prof. Osborn,[1] while they differ considerably from the lower teeth doubtfully referred by Dr. Schlosser[2] to that genus. The chief difference between the molars and those of the *Phiomys* of Osborn seems to be that the incomplete crest, running on from the postero-internal side of the protoconid, is less developed than in that genus. In *Metaphiomys*, on the other hand, it is much more strongly developed.

The dimensions (in millimetres) of this specimen are:—

Length of the crowns of the three teeth .... 10·6

	Length of crown.	*Width of crown.*
pm_4	4·0	3·8
m_1	3·4	4·0
m_2	3·8	4·2

Measurements taken at the grinding-surface.

Dr. Schlosser has shown that *Phiomys* is a member of the Theridomyidæ, approximating in tooth-form to various species of *Theridomys* and *Trechomys*, and the species here described may be regarded as belonging to a new genus of the same family, its specific name being *Paraphiomys pigotti*, gen. et sp. nov., after the late Mr. D. B. Pigott, who was the first to collect bones in this locality. It may have been derived from *Phiomys* or some allied form, having undergone an increase in size and a reduction of the transverse ridge mentioned above.

Of the recent forms inhabiting Africa, the Cane-Rats seem to approach this type most nearly in tooth-form. For instance, in *Thryonomys* the molars are similar, but have entirely lost the extra ridge from the protoconid, and the premolar is larger and more complicated. Much more material is required before the question of any actual relationship can be settled.

Order CARNIVORA.

This order is represented by a portion of the left ramus of a mandible and a left astragalus.

The mandibular ramus (Pl. XXIX, figs. 1 *a* & 1 *b*), from Bed 31 at West Kachuku, is unfortunately incomplete posteriorly, all behind the last premolar having been broken away. That portion of the ramus which is preserved deepens at the symphysis, partly on account of the upward curve of its upper border, but partly also owing to the slight downward curve of the ventral border to the rounded and thickened chin. There are two foramina on the

[1] Bull. Am. Mus, Nat. Hist. vol. xxiv (1908) p. 269.
[2] Beitr. Paläont. Œsterr.-Ung. vol. xxiv, pt. 2 (1911) p. 91.

outer face of the bone—the larger a little anterior to pm_2, the other beneath pm_3.

The teeth preserved are an incisor (fig. 1 *a*, *i.*), apparently the outer one, the canine (*c.*), and two premolars (pm_3, pm_4), the small pm_2 being represented by its root only. The incisor has its crown strongly compressed from side to side towards its base, while the summit forms a backwardly curved hastate point. The canine is not very big; its inner face is nearly flat, and is separated from the strongly convex anterior and outer face by well-defined ridges, the hinder of these forming the sharp posterior edge of the tooth, which is finely crenulated from the base nearly to the point. Behind the canine is a diastema, in which the upper border of the jaw rises towards the front; behind this, again, is the root of the small compressed pm_2, which in turn is separated by a short interval from pm_3. Pm_3 consists of a high, laterally compressed, anterior cusp, behind which and towards the outer side of the tooth is a small tubercle surrounded posteriorly and internally by a strongly developed cingulum. Pm_4 is a considerably bigger tooth; it consists of a large central cusp, much compressed and having sharp anterior and posterior edges, a small blunt anterior tubercle, and a compressed posterior cusp, the cutting-edge of which is in line with the edge of the main cusp, from which it is separated by a sharp notch; behind this is a small talon formed by the cingulum.

This mandible seems to have belonged to a feline Carnivore, nearly related probably to *Pseudælurus* or *Ælurictis*. From *Ælurictis* it is distinguished by the absence of a sharp angulation of the chin, the smaller size of pm_2, and its greater distance from the canine in front and from pm_3 behind. From *Pseudælurus* it is distinguished by the somewhat greater depth of the chin and the greater length of the diastema between the canine and the second premolar. There is, however, in the British Museum collection a mandible referred to *Pseudælurus* in which these differences are not very great, and the present specimen may be provisionally referred to that genus under the name of ***Pseudælurus africanus***, sp. nov.

The dimensions (in centimetres) of this specimen are:—

Length, so far as preserved	5·7
Depth of symphysis at canine	2·6
Depth of ramus beneath pm_4	2·1
Distance between canine and pm_3	2·0
Length of pm_3	1·1
Width of pm_3	0·5
Length of pm_4	1·4
Width of pm_4	0·6

The left astragalus (Pl. XXIX, fig. 2) of a Carnivore, about as big as a lion, presents some peculiar features. The specimen, which is from Bed 31 at Kachuku, is considerably abraded at the edges, but shows the chief characters very well. The surface for the tibia is oblique, and but slightly concave from side to

side; at its lower posterior border is the upper opening of the astragalar canal, the lower aperture (*f.*) of which lies in a deep pit between the posterior end of the ectal (*ect.*) and sustentacular (*sus.*) facets for the calcaneum. The fibular facet is nearly flat, and in the anterior half of its lower border it forms an obtuse angle with the anterior part of the ectal facet; posteriorly, the two surfaces are separated by a deep groove, terminating anteriorly in a foramen, a condition also seen in the astragalus of *Apterodon.* The inner face of the body of the bone beneath the tibial surface is concave, but ventrally it is produced into a considerable tuberosity. The neck is long, and the head bears a convex navicular facet; but its borders are much broken and the actual form uncertain. The elongated ectal facet is placed very obliquely, and is concave in the direction of its length; it is separated from the sustentacular facet by a deep valley, which terminates postero-internally in the astragalar foramen, while antero-externally it widens out. The sustentacular facet is rhomboidal in outline, and is gently convex.

Comparison with the astragali of other Carnivora shows that this specimen is much like the astragalus of the Felidæ. In these, however, except in the Machærodontinæ, there is no astragalar perforation, and comparison with an astragalus of *Smilodon* shows that in this genus, and probably therefore in other genera of Machærodonts, the neck of the bone is much shorter than in the specimen now described. Very considerable similarity to the astragalus of *Apterodon macrognathus* from the Upper Eocene of Egypt[1] is also noticeable. It seems, therefore, likely that this bone may either belong to a big and probably primitive feline Carnivore, or to a large Creodont surviving in this region after the group had died out elsewhere.

The dimensions (in centimetres) of the specimen are:—

Greatest length	6·3
Greatest width	5·1
Width of tibial surface (approximate)	3·3

Order CHELONIA.

Group Cryptodira.

This group of Chelonians is represented by portions of a large and massive carapace and plastron (Pl. XXVII, fig. 4) belonging to a species of *Testudo.* The most important fragment, from Bed 31, at Kachuku, consists of the anterior half of a plastron with parts of the right axillary buttress and of the antero-lateral border of the carapace. The plastron, so far as it is preserved, is very similar to that of *Testudo pardalis*, but belonged to an individual larger and possessing a more massive shell than is found in this recent species. On the right side the suture between the hyo- and hypo-plastra is preserved, and if this suture is in the same relative position as in

[1] Brit. Mus. Catal. 'Tertiary Vertebrata of the Fayûm' 1906, p. 231.

Testudo pardalis, the length of the complete plastron must have been about 84 centimetres.

The epiplastra (*Epi.*), which form a slight projection at the anterior end of the plastron, are greatly thickened, and, as in *T. pardalis*, bear on their upper surface a strong prominence, which is deeply hollowed out posteriorly to form a high lip. The entoplastron (*Ent.*) is lozenge-shaped, its transverse diameter being the longest. In the middle line on its upper surface is a strong ridge, produced posteriorly into a pointed process, which seems to have projected behind the rest of the bone. On the ventral face of the plastron, the postero-lateral borders of the entoplastron are marked by strong grooves, as if a line of division in the epidermal shields occurred there. The hyoplastra (*Hyo.*) seem to have been relatively longer than in *T. pardalis.*

The paired gular shields (*g.*) are very short; they cover the projecting portions of the epiplastra, and their posterior angle is considerably in front of the anterior angle of the entoplastron. This last character distinguishes this species from all with which it has been compared, except *T. perpiniana* Depéret & Donnezan[1] from the Pliocene of Roussillon. From this, however, the species here described is distinguished by the form of the epiplastra. In consequence of the small size of the gulars, the humeral shields (*hum.*) appear very large; the line of union between them and the pectorals is straight, and passes immediately behind the posterior angle of the entoplastral bone. The peculiar grooves running along the hinder border of this bone, and perhaps indicating a partial division of the humeral shields, have been mentioned above.

The pectoral shields (*pect.*) are very short from before backwards; they are widest at their median ends, and narrow outwards almost to a point. The boundary between the abdominal and the femoral shields is not preserved.

This Chelonian may best be referred to the genus *Testudo*, although it is possible that, when the whole shell is known, it will be found necessary to separate it. It may be, for the present, called *Testudo crassa*, sp. nov.

Some dimensions (in centimetres) of this specimen are:—

Estimated total length	84·0
Width immediately in front of the axillary buttress	39·5
Length of the entoplastral bone	16·2
Width of the same	19·4

An imperfect left scapula of a Chelonian of gigantic size may here be mentioned. The specimen is from Karungu, probably from the Lower Miocene deposits, and was sent to the British Museum by Mr. C. W. Hobley, C.M.G. It is rather larger than the corresponding bone of a skeleton of *T. gigantea* Schweigg. from Aldabra, the shell of which is about 123 centimetres long in

[1] Mém. Soc. Géol. France: Paléontologie, vol. iv, Mém. 3 (1893) pl. [ii] xv, fig. 2.

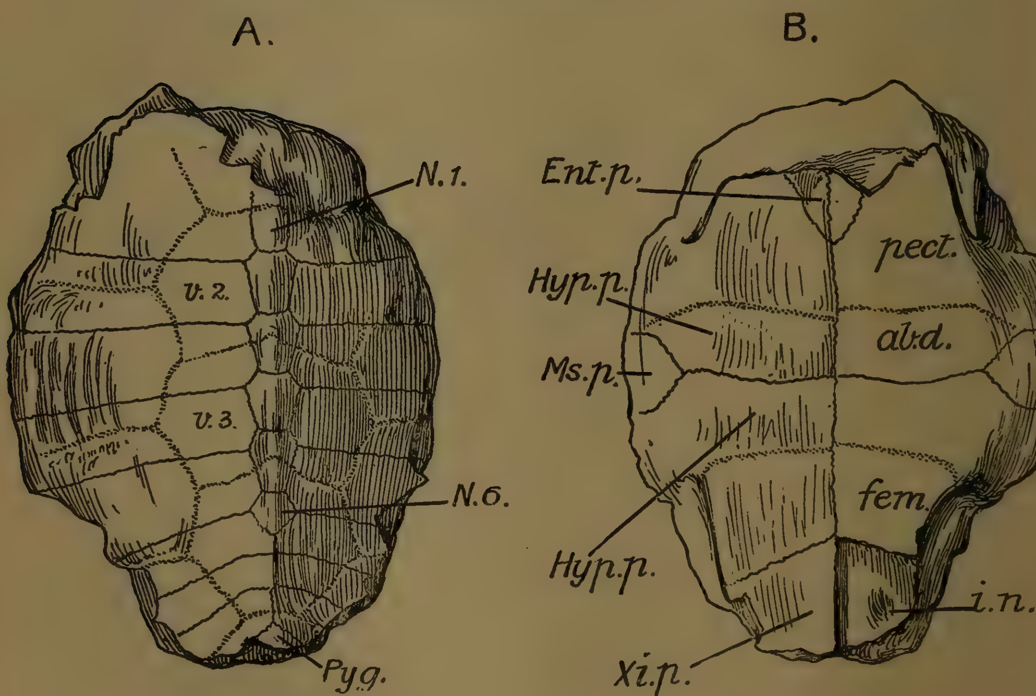
a straight line. If this scapula belonged to *Testudo crassa*, it indicates that that species sometimes attained a much greater size than the type-specimen. The long diameter of the glenoid cavity of this specimen is about 9 centimetres, the same as in the scapula of *T. gigantea*, above referred to.

There are some fragments of a very massive shell, which probably belonged to one of these gigantic individuals.

Group Pleurodira.

This group is represented by an incomplete shell of a very young individual (fig. 3, below) of a species of *Podocnemis* from Bed 22 at Kachuku. The specimen is imperfect peripherally, all the

Fig. 3.—*Shell of a species of* Podocnemis *from Bed 22 at Kachuku, about three quarters of the natural size.*



A = Carapace. B = Plastron.

marginals being lost. There are six neurals, of which the first five are hexagonal in outline, with the antero-lateral side short; the sixth is pentagonal, and its posterior angle projects between and partly separates the inner ends of the sixth pair of costals; while the seventh and eighth pairs of costals meet in the middle line. As in the young of several species of *Podocnemis*, the neurals bear a slight keel-like median ridge, most highly developed on the fourth and fifth. The form of the epidermal shields will be best understood from the figure.

The plastron (fig. 3, B) is incomplete, the anterior and posterior ends being broken away. The characteristic lateral mesoplastra (*Ms.p.*) are well preserved. The left xiphiplastral (*Xi.p.*) has come away from the matrix, and its impression shows that its upper surface bore a roughened facet for union with the pubis, as usual in the group.

No living species of this genus is now found in Africa, but several have been described from the Upper and Middle Eocene of the Fayûm (such as *Podocnemis antiqua*, *P. fajumensis*, *P. stromeri*[1]) and from the Lower Miocene of Moghara (*P. ægyptiaca*[2]). The specimen here described resembles the type of *P. ægyptiaca* in many respects, and, moreover, is from a bed of the same age. For the present, therefore, it will be best to regard it as a young individual of that species. Both specimens are very similar to individuals of *P. madagascariensis* of corresponding ages.

Group Trionychoidea.

The greater part of the carapace of a species of *Cycloderma* was obtained from Bed 21 at Kachuku. The parts preserved are: the nuchal bone; the seven anterior neurals and part of the eighth; all the costals on the right side—except the outer end of the second, while on the left side the second, the seventh, and parts of some others are wanting. The surface of the carapace seems to have been moderately convex; its anterior (nuchal) border is slightly concave, but beyond this the outline is broadly convex, the shell widening as far back as the third costal. Behind this it narrows to the seventh costal, where its border is even slightly concave; from this point it is evenly convex to the postero-lateral convexities, between which the posterior border is slightly concave. (See Pl. XXVII, fig. 1.)

The nuchal is considerably wider than long, and its anterior border is slightly concave. From about the middle of its ventral face, a short distance on each side of the middle line, a pair of strong ridges curve outwards and apparently terminated in a plate-like process overlapping the anterior part of the ventral face of the first costal; this ventral plate of the nuchal is separated from the edge of the main body of the bone by a sharp notch. There seems to have been no emargination of the posterior border for the reception of the anterior end of the first neural.

There were eight neurals. The anterior two are between the first costals; they are of peculiar form, the first, which may perhaps be regarded as a pre-neural, being asymmetrically developed as a small irregularly-hexagonal plate, bounded on the left by the left costal, but almost completely cut off from the right costal by an

[1] Ann. Mag. Nat. Hist. ser. 7, vol. xi (1903) p. 115, and A. von Reinach in Abhandl. Senckenb. Naturf. Gesellsch. vol. xxix (1903) p. 1; see also E. Dacqué in Geol. Paläont. Abhandl. Jena, vol. xiv (1912) p. 308 [36].

[2] Geol. Mag. dec. 4, vol. vii (1900) p. 1.

anterior prolongation of the second neural. This has short postero-lateral borders for union with the second costals; while, owing to the asymmetry above noted, the right antero-lateral border for the first costal is much longer than the left. Neurals 3 to 7 are hexagonal, the postero-lateral borders being the shortest. The eighth is small, and is longer than broad; it nearly, or perhaps completely, separates the inner ends of the seventh costals; but whether it extended at all between the eighth costals cannot be seen.

The first costal is the largest, and widens out to a considerable extent towards its outer end, although, owing to the large size of the nuchal, to a less degree than in the recent members of the genus. The fourth costal is the narrowest, and is almost of the same width throughout. The seventh costals, as noted above, are probably completely separated by the last neural, while the eighth meet in the middle line and together form the slightly concave posterior border of the shell. The ribs were very thin, and where fused with the costal plates form no noticeable prominence; their thin free outer ends are broken, but (even when complete) probably did not project beyond the edge of the carapace.

The sculpture consists of numerous tubercles, which, on the costals, tend to fuse into ridges running for the most part parallel to the edge of the plates, and are best developed near the edge of the shell. The sculpture of the neurals is less distinct, but here also the tubercles tend to form ridges, which in this case are more irregularly arranged. (See Pl. XXVII, figs. 2 & 3.)

This specimen was at first regarded as a species of *Trionyx*, but it is distinguished from members of that genus by (1) the general outline of the shell, particularly of the posterior border, (2) the form of the nuchal bone, and (3) the nature of the sculpture. In all these points, and in its structure generally, it agrees very well with the two recent species of *Cycloderma* (*C. frenatum* Peters, from the Zambesi and the Congo, and *C. aubryi* A. Dum., from the Gaboon and the Ogowe). On the other hand, it is distinguished from these species by the larger nuchal and the consequently smaller first costal; and in the arrangement of the neurals, even if the asymmetry of the anterior two is regarded as an individual peculiarity, there are many differences in detail. It is proposed, therefore, to make this specimen the type of a new species, for which the name *Cycloderma victoriæ*, sp. nov., is proposed.

The dimensions (in centimetres) of this specimen are:—

Length of shell in the middle line	34·3
Length of nuchal in the middle line (approximate) ...	4·4
Width of nuchal	16·8
Greatest width of shell	30·7

The only other portion of the shell of this Chelonian that is preserved is a plate of the plastron (hyo-hypoplastron) of a young

individual from Bed 31 at Kachuku; in this the sculpture is quite similar to that of the type carapace.

The collection also includes some fragments of the shell of a species of *Trionyx* with fine vermiculate sculpture, but the remains are insufficient for determination. There is, too, a fragment of the middle of a large carapace bearing a sculpture of numerous shallow pits; this may indicate the presence of a form allied to *Chitra indica.*

Order CROCODILIA.

The Crocodiles are represented by teeth, scutes, and a few fragments of bones. One type of tooth is thick and blunt-crowned, almost circular in section, but with distinct anterior and posterior carinæ; the enamel is raised into fine wrinkles. These teeth probably belong to a Crocodile much like the recent *Cr. niloticus.* There are also some slender conical teeth with very sharp points, and a somewhat curved crown covered with enamel, raised at regular intervals into well-marked ridges running from base to tip; in some cases, there are slightly developed anterior and posterior carinæ. This type of tooth probably belonged to a long-snouted gavial-like form, not otherwise represented in the collection, except perhaps by some fragments of maxilla.

Finally, among a number of small teeth collected in Bed 24 there is one with a somewhat compressed lanceolate crown, the edges of which, except at the worn tip, bear a fine serration at right angles to the border (Pl. XXVIII, fig. 8). This tooth is extraordinarily like those of some Carnivorous Dinosaurs (for instance, *Thecodontosaurus*); as it shows no signs, however, of derivation from older beds, it can hardly belong to a member of that group, but is most probably Crocodilian. Somewhat similar serrated teeth have been described by Cuvier[1] as belonging to a Crocodile, remains of which are common in Eocene beds near Argenton. J. E. Gray[2] subsequently called this species *Crocodilus rollinatii*, but afterwards it was referred to a separate genus *Pristichampsa* by P. Gervais.[3] In this the teeth are similarly compressed and serrated, and it seems likely that the specimen here described indicates the survival in Africa of a similar type of Crocodile until the Miocene Period. Possibly some of the strongly sculptured scutes, the smaller vertebræ, and other bones may belong to the same animal.

[1] 'Recherches sur les Ossemens fossiles' 2nd ed. vol. v, pt. 2 (1824) p. 166 & pl. x, figs. 14–17, 21, 22.

[2] 'Synopsis Reptilium' 1831, p. 61.

[3] 'Zoologie & Paléontologie Françaises' 2nd ed. (1859) p. 446 & pl. lvii, figs. 19–21, pl. lix, figs. 3–5.

EXPLANATION OF PLATES XXVII–XXIX.

[All the specimens are in the British Museum (Natural History).]

Plate XXVII.

Fig. 1. Carapace of *Cycloderma victoriæ*, sp. nov., type-specimen; a quarter of the natural size. (See p. 183.)
2. Sculpture of neural bone of *Cycloderma victoriæ*; natural size.
3. Sculpture of costal bone of *Cycloderma victoriæ*; natural size.
4. Imperfect plastron of *Testudo crassa*, sp. nov., type-specimen; a fifth of the natural size. (See p. 180.)

abd., abdominal shield; *Ent.*, entoplastral bone; *Epi.*, epiplastral bone; *g.*, gular shield; *hum.*, humeral shield; *Hyo.*, hyoplastral bone; *Hyp.*, hypoplastral bone; *Nu.*, nuchal bone; *pect.*, pectoral shield; *Pyg.*, pygal bone.

Plate XXVIII.

Fig. 1. Right lower first molar of *Dinotherium hobleyi* Andrews; two-thirds of the natural size. (See p. 165.)
2. Right upper premolar of the same; two-thirds of the natural size.
3. Third right upper molar of a Rhinoceros; two-thirds of the natural size. (See p. 176.)

Figs. 4 *a* & 4 *b*. Portion of left ramus of mandible of *Myohyrax oswaldi*, gen. et sp. nov., type-specimen; four times the natural size. Fig. 4 *a*. Crown view of teeth. Fig. 4 *b*. From the inner side. (See p. 169.)

Figs. 5 & 5 *a*. ? Third lower molar of the same; four times the natural size. Fig. 5. Crown view. Fig. 5 *a*. From the side. (See p. 170.)

Figs. 6 *a* & 6 *b*. Upper molar of the same; four times the natural size. Fig. 6 *a*. Crown view. Fig. 6 *b*. From the front. (See p. 170.)

Fig. 7. Left ramus of mandible of *Paraphiomys pigotti*, gen. et sp. nov., with pm_4–m_2, type-specimen; crown view of teeth. Four times the natural size. (See p. 177.)
8. Tooth of a Crocodile (*Pristichampsa ?*). (See p. 185.)

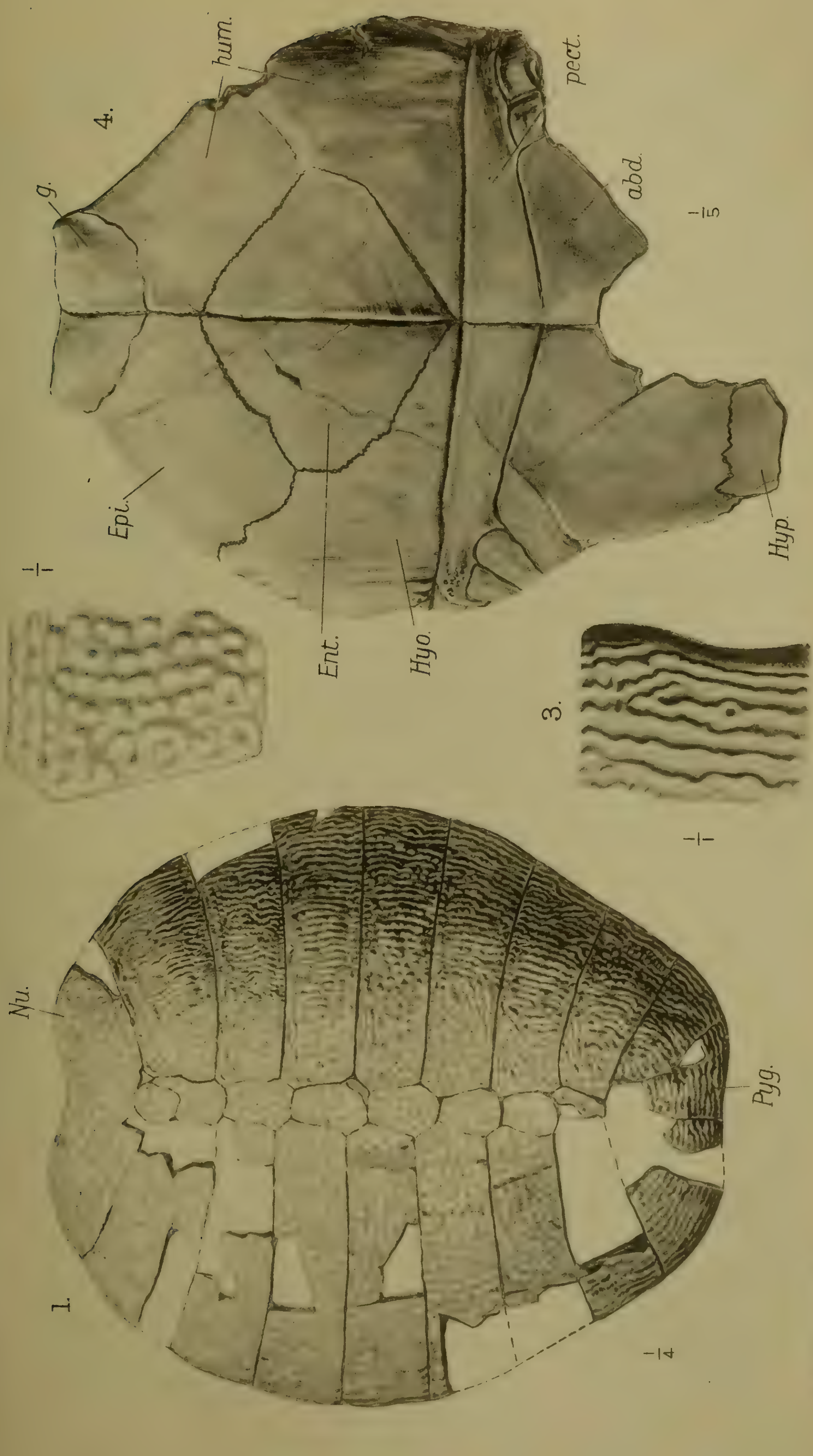
Plate XXIX.

Figs. 1 *a* & 1 *b*. Portion of a mandibular ramus of *Pseudælurus (?) africanus*, sp. nov., type-specimen; natural size. Fig. 1 *a*. From above. Fig. 1 *b*. From the inner side. (See p. 178.)

Fig. 2. Left astragalus of a (?) Creodont, from below; two-thirds of the natural size. *ect.*, ectal facet; *f.*, perforation in astragalus; *sus.*, sustentacular facet. (See p. 179.)

Figs. 3 *a* & 3 *b*. Portion of left ramus of mandible, with m_3, of *(?) Merycops africanus*, sp. nov., type-specimen; natural size. Fig. 3 *a*. From above. Fig. 3 *b*. From the inner side. (See p. 171.)

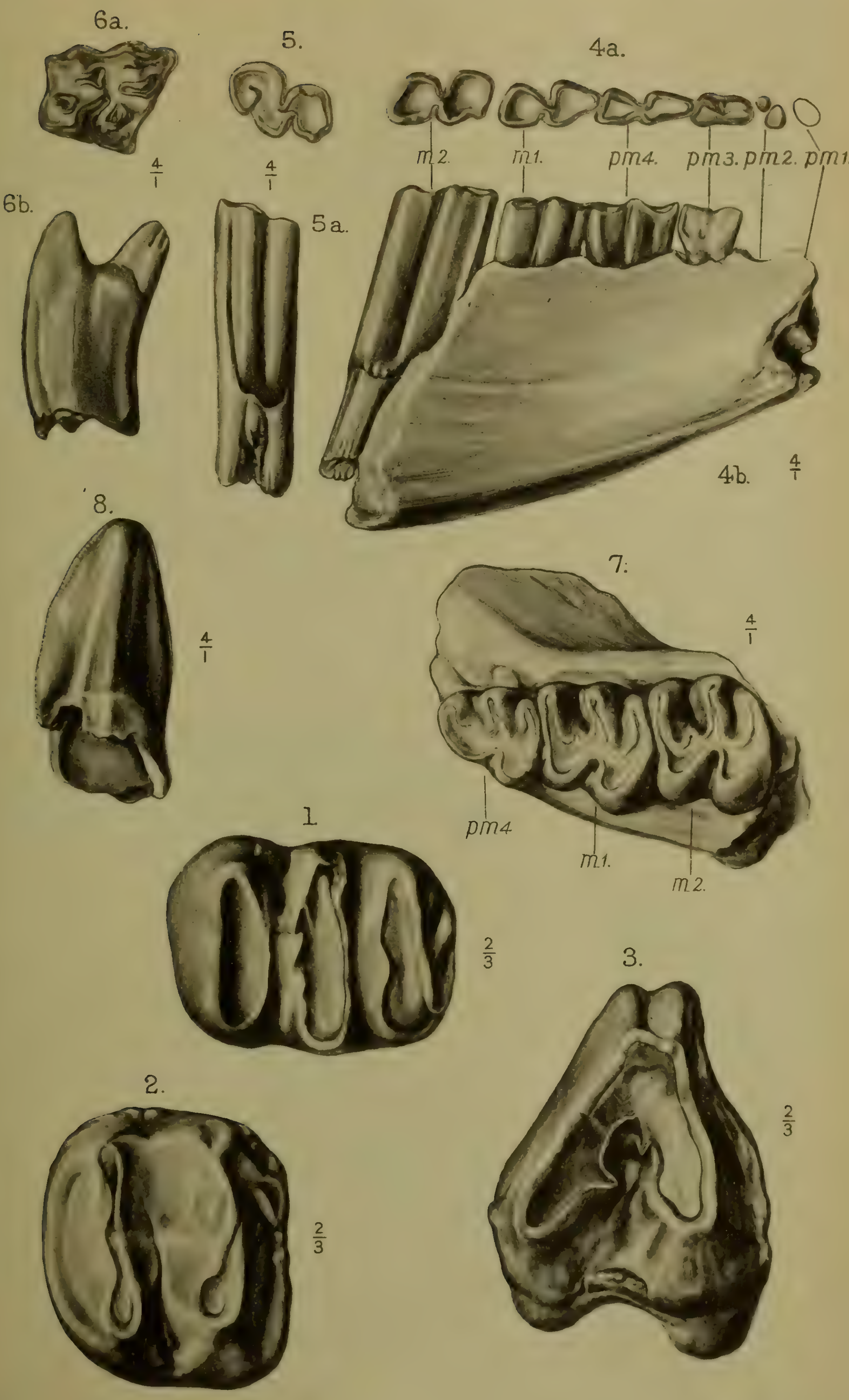
Figs. 4 *a* & 4 *b*. Lower canine tusk of (?) the same; two-thirds of the natural size. Fig. 4 *a*. From the side. Fig. 4 *b*. From above. (See p. 172.)



CHELONIA FROM THE VICTORIA NYANZA REGION.

G. M. Woodward, del.

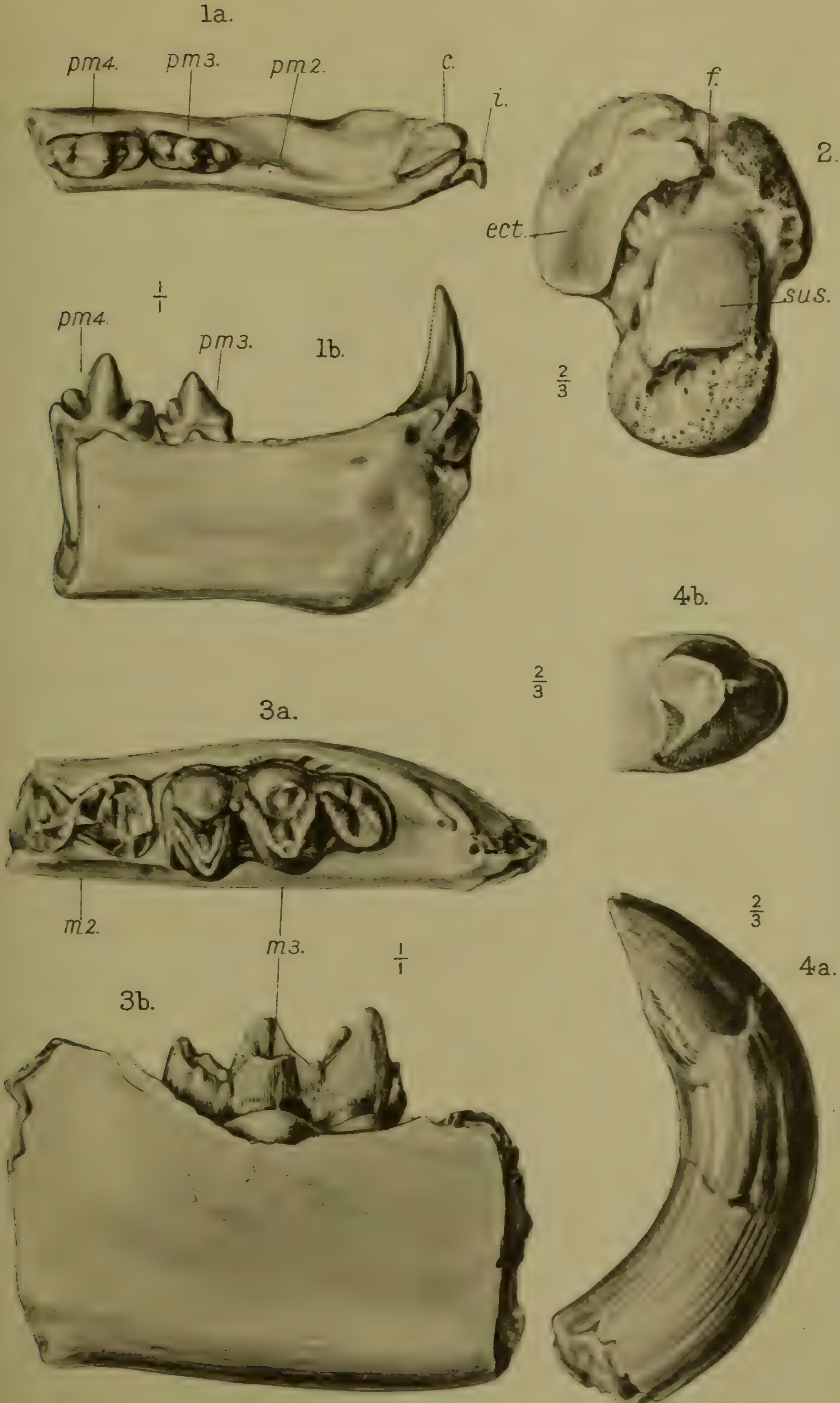
Bemrose, Collo, Derby



G. M. Woodward, del.

Bemrose, Collo., Derby

HYRACOIDEA, etc. FROM THE VICTORIA NYANZA REGION.



G. M. Woodward, del.

Bemrose, Collo, Derby.

CARNIVORA, ETC. FROM THE VICTORIA NYANZA REGION.

Appendix III.

On some Non-Marine Molluscan Remains *from the* Victoria Nyanza Region, associated *with* Miocene Vertebrates.[1]

By Richard Bullen Newton, F.G.S.

[Plate XXX.]

Introduction.

The material on which this communication is based was obtained by Dr. Felix Oswald from a series of fluvio-lacustrine deposits occurring at Nira, Kachuku, and Kikongo, which are situated east of Karungu Bay, and therefore near the north-eastern corner of the Victoria Nyanza, the furthest-removed locality from the lake-margin being Kikongo, which is distant some 5 or 6 miles.

From geological observations made at these places, Dr. Oswald was able to construct a vertical section showing that the rock-succession was divisible into thirty-seven beds of variable thicknesses, which, when added together, amounted to a total thickness of about 160 feet. Speaking generally, the mollusca were found throughout the deposits, and often in association with a small species of *Dinotherium*, and Chelonian, Crocodilian, and other vertebrate remains. The most valuable of these fossils was the *Dinotherium*, because it unmistakably indicated that the deposits containing it might be referred to the Burdigalian stage of the Miocene Period. Stratigraphically, then, this was an important result; but it had been arrived at previously to the 'Oswald' expedition by Dr. C. W. Andrews, F.R.S.,[2] who reported on similar *Dinotherium* remains from the same area, which had been collected by the late Mr. D. B. Pigott, and were afterwards presented to the British Museum by Mr. C. W. Hobley, C.M.G., one of the Commissioners for British East Africa. From a fragmentary mandible with teeth *in situ*, Dr. Andrews was enabled to recognize a new species of this genus, figuring and describing it as *D. hobleyi*, as well as pointing out its affinities and ranking it as 'closely similar to *D. cuvieri*' of Kaup, a characteristic mammal of the Burdigalian beds of France.

It is fortunate, therefore, that the vertebrate evidence enables us to determine so accurately the horizon of the deposits, because the molluscan remains would have utterly failed in this direction, from the fact that they represent existing species. The collection consists entirely of gastropod genera of fluviatile and terrestrial character belonging to *Ampullaria*, *Lanistes*, *Cleopatra*, *Tropidophora*, *Achatina*, *Burtoa*, *Cerastus*, and *Limicolaria*—the total absence of Pelecypoda being incidentally mentioned as remarkable, since

[1] Communicated by permission of the Trustees of the British Museum.

[2] 'On a New Species of *Dinotherium (D. hobleyi)* from British East Africa' Proc. Zool. Soc. London, 1911, p. 943 & pl. xlviii.

the group is so well represented in the waters of the Victoria Nyanza at the present day.

The more abundant shells are the freshwater genera *Ampullaria*, *Lanistes*, and *Cleopatra*; whereas the remaining or terrestrial forms are few, and appear to be extremely rare. So far as past distribution is concerned, only three of the species have been previously recorded from geological deposits: namely, *Ampullaria ovata* and *Lanistes carinatus*, both of which occur in the late post-Pliocene beds of Egypt (Fayûm); and also *Tropidophora nyasana*, which has been found in beds of similar age on the Lake Nyasa plateau. Among the freshwater forms, only the *Ampullaria* is known as living in the Victoria Nyanza, while the nearest water for *Lanistes carinatus* appears to be the Tana River, a considerable distance east of that lake. Lake Rudolf and the Mombasa-Zanzibar waters are the nearest available regions for obtaining *Cleopatra bulimoides*, while *C. exarata* is found only in the last-named district. The land-shells are mostly restricted to the Nile and lake countries of Eastern Africa. In the following table the distribution is set out more fully :—

TABLE SHOWING THE DISTRIBUTION OF THE SHELLS COLLECTED BY DR. OSWALD.

Genera and Species.	Fossil.			Recent.										
	Miocene (Karungu).	Post-Pliocene (Fayûm).	Post-Pliocene (Nyasa).	Lake Mareotis and region.	Birket el Qurun.	Nile regions.	Abyssinia.	Somaliland.	Lake Rudolf.	Victoria Nyanza.	Tanganyika.	Tana River.	Mombasa-Zanzibar region.	Nyasa.
Freshwater.														
Ampullaria ovata	×	×	...	×	...	×	...	...	...	×	×	...	...	×
Lanistes carinatus	×	×	...	×	×	×	×	...	...	...	...	×		
Cleopatra bulimoides	×	...	...	×	...	×	×	...	×	...	...	...	×	
Cleopatra exarata	×	...	...	...	...	...	...	...	...	...	...	...	×	
Terrestrial.														
Tropidophora nyasana	×	...	×	...	...	...	...	...	...	...	...	...	...	×
Achatina sp.	×													
Burtoa cf. *nilotica*	×	...	...	...	...	×	...	...	...	×	×	...	...	×
Cerastus cf. *mœllendorffi*	×	...	...	...	...	...	×	×						
Cerastus sp.	×													
Limicolaria sp.	×													

In no other region of Africa has a similar molluscan fauna of this age been found, the only Burdigalian beds known being those of Moghara [1] and Wadi Faregh [2] in Egypt. They are, however, differently constituted, having involved marine as well as estuarine conditions in their formation, as proved by their fossil contents, which consist of marine mollusca, echinoids, polyzoa, etc., as

[1] C. W. Andrews, Geol. Mag. dec. 4, vol. vi (1899) pp. 481, 482.
[2] E. Stromer, Abhandl. Senckenb. Naturf. Gesellsch. vol. xxix (1907) p. 83.

well as land-animals (*Podocnemis*, *Brachyodus*, etc.), and plants (palms). Certain sandstone-beds in the Moghara region are intercalated with marine and terrestrial deposits, and are full of the small *Paludestrina* (= *Hydrobia*): hence Dr. M. Blanckenhorn[1] has regarded them as equivalent in age to the 'Hydrobien-Schichten' of Europe, which is part of the Burdigalian stage of the Miocene.

It would seem, therefore, according to Dr. Oswald's[2] preliminary account, that the deposits in question represent the delta of an old river which, during Lower Miocene or Burdigalian times, ran into the Victoria Nyanza at Karungu. The present molluscan evidence would indicate that the genera *Lanistes* and *Cleopatra* formed part of the lake-fauna at that period, although they have since become extinct in those waters, only the *Ampullaria* surviving to the present day. Among the terrestrial shells, *Burtoa* is the sole genus found in the neighbourhood of the lake, whereas the others occur in localities at considerable distances therefrom. Finally, it may be stated that the molluscan remains consist largely of natural casts in clays, marls, and sandstones of different shades of colour, the prevailing tint being grey; there are, besides, occasional specimens which are better preserved, and in which the details of shell-structure can be seen.

I desire to thank my friend Mr. Edgar A. Smith, I.S.O., of the British Museum, for advice and assistance during the preparation of these notes.

Description of the Specimens.

Freshwater Forms.

Family Ampullariidæ.

Ampullaria ovata Olivier. (Pl. XXX, figs. 1–4.)

Ampullaria ovata Olivier, 'Voy. Emp. Othoman, Égypte, Perse' 1804 (An 12) vol. iii, pl. xxxi, fig. 1 & p. 67: E. von Martens, 'Beschalte Weichthiere Ost-Afrikas—Deutsch-Ost-Afrika' (K. Möbius) vol. iv (1898) p. 158; E. A. Smith, Proc. Malac. Soc. London, vol. vi (1904) p. 100.

Pachylabra ovata Kobelt, Kuster's 'Conchyl.-Cabinet' pt. 556 (1912) p. 46.

Original diagnosis:—*Oblongo-ovata, subcarnea, intus alba; umbilico angusto, recurvo; margine columellari obtecto.*

Remarks.—The specimens referred to this species consist mostly of matrix-casts of various sizes, with more or less imperfect and fractured margins. In adult forms the spiral region would appear to be rather more produced than in smaller specimens—although the relative proportions are similar, and entirely agree with what obtains among living shells brought home by Dr. Oswald from the waters of the Victoria Nyanza. A few of the smaller or intermediate examples have some shell-structure preserved, in which the longitudinal striations can be traced; but there is no evidence of the spiral bands.

[1] Zeitschr. Deutsch. Geol. Gesellsch. vol. liii (1901) p. 102.

[2] 'Daily Telegraph' April 5th, 1912, and Geogr. Journ. vol. xli (1913) p. 114.

Occurring with these specimens are a number of isolated opercula of large, thick, and robust character, and, moreover, of calcareous structure. Only one fragmentary example is observed to be more or less *in situ*, covering the broken aperture of one of the smaller forms of this species.

Dimensions in millimetres:—

Shell { Height varying from 18 to 45.
Diameter (maximum) varying from 15 to 45.

Operculum { Height=33.
Width=20.

Distribution.—Although there are no records of the existence of this species in the waters of Birket el Qurun, it occurs in the late post-Pliocene deposits of that district of Egypt (examples are preserved in the British Museum and in the Cairo Museum). Besides the original locality of Lake Mareotis, this mollusc has been found in the region of the White Nile, the Victoria Nyanza, Lakes Tanganyika and Nyasa, as well as in parts of Portuguese West Africa.

Occurrence.—The specimens were mostly discovered in Beds 14 & 15, associated with remains of Chelonia, Crocodilia, and *Lanistes carinatus*. More isolated examples are represented from the following beds:—

Bed 16. Opercula only—associated with Hyracoid, Crocodilian, and Chelonian remains and *Cleopatra*.

Bed 17. }
Bed 19. } Accompanying Chelonia and Crocodilia.

Bed 21. With *Lanistes carinatus*, and vertebrates similar to those found in Bed 17.

Bed 24. Opercula only—with *Dinotherium* and other vertebrates.

Bed 31. With *Dinotherium* and other vertebrates.

Bed 32. With *Lanistes carinatus* and *Cleopatra*.

Bed 34. An isolated cast in brown marlstone.

Localities.—Nira (Beds 14, 15, 19, 24, 31, 32, 34); Kachuku (Beds 14, 15, 16, 17, 21, 24); Kikongo (Bed 14).

LANISTES CARINATUS (Olivier). (Pl. XXX, figs. 5–7.)

Helix terrestris bolteniana contraria Chemnitz, 'Conchylien-Cabinet' vol. ix (1786) p. 89 & pl. cix, figs. 921–922.

Ampullaria carinata Olivier 'Voy. Emp. Othoman, Égypte, Perse' 1804 (An 12) vol. iii, pl. xxxi, fig. 2 & pp. 67, 68.

Lanistes olivieri Montfort, 'Conchyliologie Systématique' vol. ii (1810) p. 123 (=*carinatus* Olivier).

Lanistes carinatus E. von Martens, 'Beschalte Weichthiere Ost-Afrikas—Deutsch-Ost-Afrika' (K. Möbius) vol. iv (1898) p. 169.

Meladomus (Lanistes) carinatus Kobelt, Kuster's 'Conchyl.-Cabinet' pt. 550 (1911) p. 19.

Lanistes carinatus R. B. Newton, Proc. Malac. Soc. London, vol. x (1912) p. 75.

Remarks.—The principal characters of this species are well epitomized in Olivier's diagnosis of 1804:—'AMPULLARIA CARINATA: *sinistra, depresso-turbinata; umbilici maximi margine carinato; apertura suborbiculata.*' For the more modern inter-

pretation of the shell, however, it is necessary to consult the figures and description of Dr. W. Kobelt as published in 1911, although exception must be taken to that author's recognition of it under the genus *Meladomus*.[1] It is more correct to regard *Meladomus* as embracing those species of reversed shells allied to *Lanistes* that have produced spires, and are besides mostly imperforate or simply furnished with a slit-like opening—as opposed to the true *Lanistes*, which exhibits a spreading and depressed spiral region, as well as a deeply-excavated umbilical cavity. The present species, therefore, to which the fossils are referred, forming the type of *Lanistes* of D. de Montfort, 1810, should not be mistaken for a member of Gray's later genus, *Meladomus*. The fossils, numerously represented in the collection, consist chiefly of matrix-casts, composed of dull greyish clays or marls frequently tinged or mottled externally with dark reddish brown.

They are particularly characteristic of Beds 14 & 15, being also found in Beds 21, 22, & 32, although much less sparingly and of smaller size. Occasional shell-structure has been preserved, in which the finely-carinate sculpture of the spire can be traced together with the growth-striations. As in the recent shell, the peripheral carina of the fossil form gradually disappears in its later development, the last whorl exhibiting considerable inflation and roundness. The height of the spiral region may also be mentioned, as showing slight variation both in recent and in fossil examples. It is a significant fact that no opercula of this mollusc have been found, their absence being probably due to the extremely delicate character of that organ, as also on account of its corneous texture, which would favour its entire dissolution during the processes of fossilization.

Distribution.—This species is known from the younger post-Pliocene deposits of the Fayûm depression in Egypt (specimens in the British Museum and the Cairo Museum), and is found living in the Nile (near Alexandria, etc.), Birket el Qurun, Lake Dembea (Abyssinia), and the Tana River in British East Africa. It apparently does not belong to the present-day fauna of the Victoria Nyanza, no specimens having been found among a large series of shells brought back from that lake by Dr. Oswald; nor are there any examples in the British Museum collection. Dr. E. von Martens[2] has referred doubtfully to its occurrence in the Victoria Nyanza; while Mr. E. A. Smith[3] has regarded as unreliable Dr. H. Dohrn's statement[4] that the species exists in those waters. According,

[1] *Meladomus* was originally proposed by W. Swainson ('A Treatise on Malacology' 1840, p. 340), but without recognizable type or description. Its proper adoption was due to J. E. Gray (Proc. Zool. Soc. London, 1847, p. 148), who selected as its type G. B. Sowerby's *Paludina olivacea*; therefore to Gray must be accredited the authorship of this genus.

[2] 'Beschalte Weichthiere Ost-Afrikas—Deutsch-Ost-Afrika' vol. iv (1898) pp. 169, 290.

[3] Ann. Mag. Nat. Hist. ser. 6, vol. x (1892) p. 121.

[4] Proc. Zool. Soc. London, 1864, p. 117.

also, to E. von Martens, the species does not occur in either Lakes Tanganyika, Albert Edward, or Nyasa, nor has it been recorded from Lake Rudolf; the southernmost locality for the shell appears to be the Tana River in British East Africa,[1] distant probably some 600 miles east of the deposits whence Dr. Oswald collected his fossils.

Occurrence.—The specimens found in Beds 14 & 15, which are the most numerous, were associated with Chelonian and Crocodilian remains; the specimens from Bed 32 occurred with *Ampullaria* and *Cleopatra*.

Localities.—South Nira (Beds 14 & 15); Kachuku (Beds 14 & 21); Nira (Beds 14 & 32).

Family VIVIPARIDÆ.

CLEOPATRA BULIMOIDES (Olivier). (Pl. XXX, figs. 10 & 11.)

Cyclostoma bulimoides Olivier, 'Voy. Emp. Othoman, Égypte, Perse' 1804 (An 12) vol. iii, p. 68 & pl. xxxi, fig. 6.

Paludina (Cleopatra) bulimoides Troschel, 'Das Gebiss der Schnecken' 1857, vol. i, pt. 2, p. 100 (*Cleopatra*, founded on the structure of the radula, Olivier's *bulimoides* being the type); E. von Martens, 'Conchylien aus Zanzibar, &c.' Nachtr. Deutsch. Malak. Gesellsch. 1869, p. 154.

Cleopatra bulimoides Jickeli, Nova Acta Acad. Cæs. Leop.-Car. vol. xxxvii (1874) p. 240.

Original diagnosis:—*Parvulum, fusiformi-oblongum, corneum; zona fusca, umbilico angusto, apertura ovali.*

Remarks.—Upwards of a hundred specimens in various states of preservation represent this small species. They are of conical oblong contour, possessing about six convex whorls, a slightly oblique, small, and oval aperture, as well as a rather insignificant rimate perforation. The surface is marked by a series of irregular longitudinal striations, sometimes sinuated near the suture, the earliest or apical whorls being more or less angulate immediately below the suture and, moreover, furnished with strong spiral costæ. It often happens in recent examples that decortication of the apex has taken place, and thus destroyed this early spiral sculpture; it can be obscurely seen, however, in a British Museum specimen (among others in the same box) collected by Capt. S. S. Flower, at Giza, Egypt, but in the fossil examples this ornamentation is far better preserved. There appear to be no figures illustrating such sculpture, although it constitutes an important feature in the history of the species. References have been made to the unicarinated condition of the uppermost whorls both by Jickeli and by E. von Martens; but, so far as the presence of spiral costæ is concerned, such a character would appear to have hitherto escaped the notice of conchologists.

Dimensions in millimetres:—

	Complete specimen (medium size).	*Imperfect specimen of larger size (three last whorls only).*
Height	13	15
Diameter	7	8

[1] E. von Martens, Monatsber. K. Preuss. Akad. Wissensch. 1878, p. 296.

Distribution.—This is a characteristic mollusc of localities in North-Eastern Africa and was originally described from Lake Mareotis. Dr. Jickeli refers to a number of places where the shell has been found, mostly in the Nile waters. According to E. von Martens, the species is not known to exist in the Victoria Nyanza or in the other lakes of that part of Eastern Equatorial Africa; it has, however, been recorded from Lake Rudolf by Neuvillé & Anthony.[1]

Occurrence.—The specimens were found in a brownish marlstone, associated with *Ampullaria* and *Lanistes*, in Bed 32; and in Bed 31 associated with *Ampullaria* and *Limicolaria*.

Locality.—Nira.

CLEOPATRA EXARATA (E. von Martens). (Pl. XXX, figs. 8 & 9.)

Paludomus exarata & cingulata E. von Martens, Monatsber. K. Preuss. Akad. Wissensch. 1878, p. 297 & pl. ii, figs. 14–16 (=*cingulata* of the plate).
Cleopatra exarata Bourguignat, 'Moll. Afrique Équator.' 1889, p. 164; E. von Martens, 'Beschalte Weichthiere Ost-Afrikas—Deutsch-Ost-Afrika' (K. Möbius) vol. iv (1898) p. 189.
Cleopatra (Zanguebaria) exarata W. Kobelt, Abhandl. Senckenberg. Naturf. Gesellsch. vol. xxxii (1909) p. 80.

Original diagnosis:—*Testa conico-oblonga, perforata, solida, cingulis spiralibus elevatis confertis, circa* 9 *in anfr. penultimo conspicuis, ultra* 20 *in ultimo, nonnullis bifidis, sculpta, nigricans decollata*; *anfr. superstites* 4, *vix convexiusculi, sutura mediocri discreti*; *apertura subperpendicularis, oblongo-auriformis, superne acutangula, margine externo angulatim arcuato, basali auriculatim producto et effuso, columellari subdilatato, expanso, fulvicante.*

Remarks.—There are several fragmentary examples of this species, in which the characteristic and spirally-banded costæ are well preserved. The most complete specimen has escaped anything like erosion of the spire, so frequently the case among recent forms. This has a length of 15 and a diameter of 8 millimetres; it is furnished with seven or eight whorls, the protoconch being rounded smooth, and depressed, the two succeeding whorls being more or less smooth, erect, and carinated in the centre; the later whorls are of more plano-convex structure, with the exception of the last, which is elongately inflated. The peristome is incomplete, on account of the outer lip being fractured; the base is, however, well preserved, and shows the produced character of the lip of the columella, together with indications of a narrow perforation. It should be mentioned also that the cingulate costæ are crossed by innumerable, fine, microscopical striations, which give rise to a delicately-decussated surface.

Distribution.—The species appears to be restricted to the Zanzibar and Mombasa regions of Eastern Africa, the type-locality being Finboni. It does not occur in the Victoria Nyanza, although mentioned incidentally by Bourguignat in his 'Espèces Nouv. Oukeréwé & Tanganika' 1885, p. 7.

Occurrence.—Examples are found in Bed 16 in a greyish sandstone matrix, accompanied by opercula of *Ampullaria*, Hyracoid, Chelonian, and Crocodilian remains; again in Bed 19 in a greyish sandstone, associated with coprolites, Chelonian and

[1] Bull. Soc. Philom. Paris, ser. 9, vol. viii (1906) p. 275.

Crocodilian remains, and *Ampullaria*; and also in Bed 24 in a greenish-grey clay or marl.

Localities.—Kachuku (Beds 16, 19, & 24); Nira (Bed 24); South Nira (Bed 24).

Terrestrial Forms.

Family Pomatiidæ.

Tropidophora nyasana (E. A. Smith). (Pl. XXX, fig. 14.)

Pomatias nyasanus E. A. Smith, Proc. Zool. Soc. London, 1899, p. 591 & pl. xxxv, fig. 5.

Ligatella nyasana W. Kobelt, Abhandl. Senckenberg. Naturf. Gesellsch. vol. xxxii (1909) p. 78.

Tropidophora nyasana R. B. Newton, Q. J. G. S. vol. lxvi (1910) p. 242 & pl. xviii, figs. 8–9.

Remarks.—The specimen here referred to differs only from the type in possessing fewer spiral costæ, a variation which may be found to exist when one is dealing with several specimens. Such is really the case in connexion with some Quaternary forms of the species from Nyasaland, which show well-separated and equidistantly arranged costæ. The species itself is not only related to *Cyclostoma insulare* of Pfeiffer from Natal, as pointed out by Mr. E. A. Smith; but there appear to be also some close affinities with *C. letourneuxi* Bourguignat and E. von Martens's variety of the same, *stuhlmanni*, as well as with *C. delmaresi* Ancey, all of which have been well figured by E. von Martens in his 'Beschalte Weichthiere—Deutsch-Ost-Afrika' [Möbius] 1898, vol. iv, pl. ii, figs. 1, 2, & 5, pp. 4–6. Dr. Kobelt has recognized this species under the genus *Ligatella* of E. von Martens, the type of which is Müller's *Cyclostoma ligatum*, a smooth shell. Those shells therefore, like that now under discussion, possess a prominently spiral ornamentation (not present, however, on the two earliest whorls, which are smooth as in recent examples of the species), and should more accurately be regarded as belonging to Troschel's *Tropidophora* of 1847, the type of which is the *Cyclostoma cuvierianum* Petit.[1]

Distribution.—The species has been recorded from late post-Pliocene deposits near Lake Nyasa, being also found living on the Nyasa plateau at Zomba. Only related forms [previously mentioned] are known as existing in the Victoria Nyanza region.

Occurrence.—From Bed 8, associated with *Limicolaria* sp. and *Cerastus* sp.

Locality.—Kikongo.

Family Achatinidæ.

Achatina sp. indet. (Pl. XXX, fig. 12.)

Remarks.—This genus is represented in the collection by a summit fragment only, which has a height and diameter of 14 and 10 millimetres respectively. It is of short conical form, and composed of five rather plano-convex whorls, including a smooth,

[1] Zeitschr. Malakozool. [Menke & Pfeiffer] 1847, p. 44.

rounded, and obtuse apical region. There are some partly-preserved remnants of ornamentation, which appear to be quite characteristic of the genus, exhibiting a series of closely-set, irregular, and longitudinally-oblique costulations. It is probable that this fossil belonged to a species like *A. panthera* of Férussac, the well-known East African (Mombasa, etc.) shell, which might have had dimensions such as 120 by 60 millimetres.

Occurrence.—The specimen is of solid limestone, and much mineralized at the base; it was obtained from 'pale green-grey clay' in Bed 24, accompanying opercula of *Ampullaria*.

Locality.—Kachuku.

BURTOA cf. NILOTICA (Pfeiffer). (Pl. XXX, fig. 13.)

Bulimus niloticus Pfeiffer, Proc. Zool. Soc. London, 1861, p. 24 (not figured).
Limicolaria nilotica Pfeiffer, 'Novitates Concholog.' vol. iv (1870) pl. cx, figs. 1–3 & p. 5.
Achatina nilotica Jickeli, Nova Acta Acad. Cæs. Leop.-Car. vol. xxxvii (1874) p. 151.
Burtoa nilotica Bourguignat, 'Moll. Afrique Équator.' 1889, p. 89; E. A. Smith, Proc. Malac. Soc. London, vol. i (1895) p. 323.
Livinhacia nilotica E. von Martens, 'Beschalte Weichthiere Ost-Afrikas—Deutsch-Ost-Afrika' (K. Möbius) vol. iv (1898) text-figures, pp. 94–98; W. Kobelt, Abhandl. Senckenberg. Naturf. Gesellsch. vol. xxxii (1909) p. 69.

Remarks.—The specimen referred to this form is supposed to represent the summit portion of an individual that may have originally been 80 or more millimetres long. It is of helicoid appearance, and consists of four whorls which are steep and of plano-convex character; the apical region is smooth and obtuse, while the later whorls are ornamented with closely-set oblique costulations of rather irregular and wavy design, crossed by obscure spiral striations. An obtuse medio-angulation surrounds the base, which would form the junction of the succeeding whorl. The suture-line is well impressed, but slightly interrupted by the thickened ends of the costulations. The specimen is quite robust and solid, except at the basal surface, where the shell-structure becomes extremely thin and delicate, a feature most probably caused through protection by the covering of the next volution. No remains of the periostracum are preserved.

Dimensions in millimetres: length $=16$; diameter $=15$.

From its obtuse apical region and the peculiar characters of the sculpture, there is a great probability that the fossil belonged to a large Achatinoid shell, similar to *Burtoa nilotica*, a well-known species of Equatorial Africa, as has been suggested to the writer by Mr. E. A. Smith. It was this mollusc that Pfeiffer originally described and figured under *Bulimus* and *Limicolaria* respectively, and it was subsequently selected by Bourguignat as the type of his genus *Burtoa*,[1] a name which has about a month's priority of H. Crosse's genus *Livinhacia*, founded on the same type.[2]

Distribution.—*Burtoa nilotica* lives near the sources of the White Nile; as also in the region of the Victoria Nyanza, the

[1] 'Moll. Afrique Équator.' 1889, pp. 88, 89.
[2] Journ. Conchyl. vol. xxxvii (1889) p. 105.

coasts of Tanganyika, and in the country off the southern end of Lake Nyasa.[1]

Occurrence.—At the basal fracture of the specimen the rock is observed to be a light-coloured, minutely-perforated, calcareous sandstone. It was obtained from Bed 21 in association with *Lanistes* and Chelonian remains.

Locality.—Kachuku.

LIMICOLARIA sp. indet. (Pl. XXX, fig. 17.)

Remarks.—The collection contains two fragmentary examples of this genus, belonging to different individuals. One consists of a matrix-cast in which the four latest whorls have alone been preserved. This fossil, measuring 35 by 20 millimetres, is of oblong conico-turreted contour, and originally consisted of about seven volutions, the last being nearly three times the height of the penultimate; the presence of an elongate suboval aperture with a centrally-excavated columellar margin may also be noted. The second specimen represents a summit-region composed of five volutions, and measures 11 by 9 millimetres. It is furnished with a round, depressed, and smooth apex, the succeeding whorl being also smooth, while the third and fourth whorls are relatively deep, compressed, and ornamented with numerous microscopical, fine, and slightly oblique striations; the basal whorl is compressed and sloping above, carinated at the centre, moderately inflated below, and has an obliquely striated surface like the previous whorls, but smooth below the carination; aperture oval (fractured) and of small size.

The relationships of such fragmentary specimens are, of course, difficult to trace, although they would appear to be, with *Limicolaria smithi* Preston[2] a species of rather frequent occurrence on the plateau areas that border the Victoria Nyanza, Dr. Oswald having collected some recent specimens at Kisii.

Occurrence.—The summit-fragment was found in Bed 8, associated with *Tropidophora nyasana* and *Cerastus* sp.; the larger specimen came from Bed 31, accompanying *Dinotherium* and other vertebrates.

Localities.—Nira (Bed 31); Kikongo (Bed 8).

Family BULIMINIDÆ.

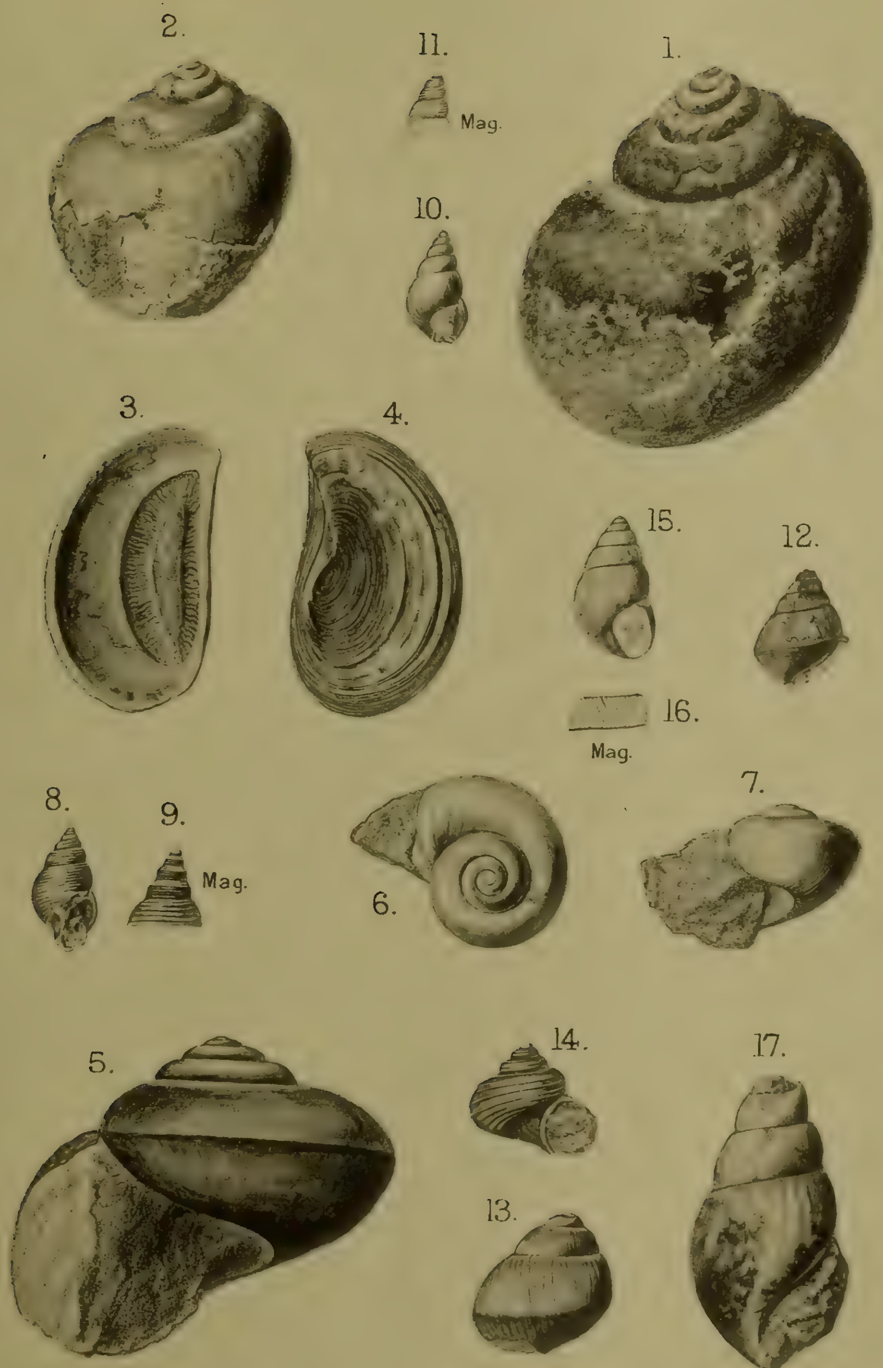
CERASTUS cf. MŒLLENDORFFI Kobelt. (Pl. XXX, figs. 15 & 16.)

Cerastus mœllendorffi Kobelt, Abhandl. Senckenberg. Naturf. Gesellsch. vol. xxxii (1909) pp. 15, 64 & pl. iii, figs. 11–15.

Remarks.—The collection includes a fairly good matrix-cast of a form of Buliminidæ which belongs undoubtedly to the genus *Cerastus* of Albers (type = *Buliminus distans* Pfeiffer), and showing, moreover, certain resemblances to *C. mœllendorffi* from Shoa and Somaliland (East Africa). The specimen is small, of

[1] E. A. Smith, Proc. Zool. Soc. London, 1893, p. 634.

[2] Proc. Malac. Soc. London, vol. vii (1906) p. 89 & text-figure.



Roland Green, del.

Bemrose, Collo., Derby

MIOCENE MOLLUSCA — VICTORIA NYANZA.

[Figures are of the natural size, except where otherwise marked.]

elongately conoidal form, and furnished with about six and a half whorls, the last being inflated and nearly double the length of the spire, whereas the spiral volutions are of plano-convex character. The aperture is suboval and of moderate proportions; it possesses a rounded outer lip, an inner lip with a central indentation, from which proceeds a straight columella having behind a well-pronounced semicircular umbilical region. Whorls obliquely costulated.

Dimensions in millimetres:—

	Aperture.
Length =15.	Length=7.
Diameter=10.	Width =5.

In general contour, in the character of the basal cavity, the presence of the straight and prominent columella, and the costulated sculpture (obscurely preserved on the dorsal surface of the penultimate whorl), the specimen corresponds with the features of this species.

Distribution.—Dr. Kobelt quotes Shoa in Abyssinia and Somaliland as areas where his species occurs.

Occurrence.—The specimen came from Bed 31 in the 'upper gravel zone,' and 'close to the *Dinotherium* jaw and other large bones.' It is of a light-coloured marly appearance, with blackish mottling.

Locality.—Kachuku.

CERASTUS sp. indet.

Remarks.—This specimen, with dimensions of 10 by 8 millimetres, is of small conical shape, made up of five depressed whorls, which are nearly in the same plane. The whorls are ornamented with a regular series of elevated and oblique costulations. Mr. E. A. Smith is of opinion that this fragment represents the summit-region of a shell like that characteristic of the genus *Cerastus*, which is probably its true interpretation, although it is quite impossible to suggest any particular species with which to associate the specimen.

Occurrence.—From Bed 8, associated with *Tropidophora nyasana* and *Limicolaria* sp.

Locality.—Kikongo.

EXPLANATION OF PLATE XXX.

[All the specimens are in the British Museum (Natural History).]

AMPULLARIA OVATA Olivier. (See p. 189.)

Fig. 1. Dorsal view of the largest specimen (natural cast). Nira (Bed 14).
2. Dorsal view of a medium-sized specimen, with the shell preserved. Nira (Bed 31).
3. Internal surface of a large isolated operculum, regarded as belonging to this species.
4. External view of the same specimen. Nira (Bed 14).

LANISTES CARINATUS (Olivier). (See p. 190.)

Fig. 5. Front view of large natural cast. Nira (Bed 14).
Figs. 6 & 7. Two views of a smaller example with the shell preserved, and showing obscure spiral angulations. Nira (Bed 32).

CLEOPATRA EXARATA (E. von Martens). (See p. 193.)

Fig. 8. Front view of well-preserved testaceous specimen.
9. Magnified view of the same, showing the early ornamentation of the spire. Kachuku (Bed 19).

CLEOPATRA BULIMOIDES (Olivier). (See p. 192.)

Fig. 10. Front view of specimen.
11. Magnified view of the same, showing spiral sculpture on the nuclear whorls. Nira (Bed 32).

ACHATINA sp. indet. (See p. 194.)

Fig. 12. Summit-fragment of individual with remains of sculpture striations. Kachuku (Bed 24).

BURTOA cf. NILOTICA (Pfeiffer). (See p. 195.)

Fig. 13. View of a well-preserved summit showing a smooth and obtuse apex, the later whorls being ornamented with oblique costulations. Kachuku (Bed 21).

TROPIDOPHORA NYASANA (E. A. Smith). (See p. 194.)

Fig. 14. Front view of specimen, showing the rounded aperture and characteristic sculpture of the species. Kikongo (Bed 8).

CERASTUS cf. MŒLLENDORFFI Kobelt. (See p. 196.)

Fig. 15. Front view of example showing aperture, etc.
16. Magnification of sculpture, obscurely preserved in the same specimen. Kachuku (Bed 31).

LIMICOLARIA sp. indet. (See p. 196.)

Fig. 17. Front view of a fragmentary specimen showing the excavated columella. Kachuku (Bed 31).

DISCUSSION.

Dr. A. SMITH WOODWARD remarked on the interest of the Author's demonstration of the great antiquity of the Victoria Nyanza. The persistence of the species of non-marine mollusca since Lower Miocene times was especially noteworthy, even if their distribution had slightly changed.

The PRESIDENT (Dr. A. STRAHAN) observed some reluctance on the part of the Fellows to discuss a region which so few had been able to visit, but he had been much impressed by the thoroughness of the work carried out by the Author in various branches of geology, and by the completeness with which he had illustrated the ground by photographs taken under circumstances of exceptional difficulty.

The AUTHOR hoped that his work on the eastern coast of the Victoria Nyanza might result in a search being instituted for similar Miocene deposits at the mouths of the other large rivers entering the lake; and he expressed his thanks to the President and to Dr. A. S. Woodward for their remarks, as also to the Fellows of the Society for their kind reception of his paper.

8. *The* GLACIAL GEOLOGY *of* EAST LANCASHIRE. By ALBERT JOWETT, D.Sc., F.G.S. (Read January 21st, 1914.)

[PLATES XXXI–XXXV.]

CONTENTS.

I. INTRODUCTION.

THE area dealt with in this paper comprises the western slopes of the Pennines from Boulsworth Hill to Blackstone Edge, together with the western offshoot from them, which separates the basin of the Ribble from that of the Mersey.

Although the treatment of the distribution of the Drift is regarded as the primary object of the paper, I also intend to examine the whole Glacial history of the district, in order that it may be viewed in relation to the larger problem of the glaciation of the Irish-Sea basin.

A brief outline of some of my conclusions was presented to the Southport meeting of the British Association in 1903.

II. THE GLACIAL DEPOSITS.

(*a*) General Appearance and Texture.

The chief characteristic of the Glacial deposits—or, as they are usually termed, the Drift—of this region is their variability. Lenticular beds of sand and gravel alternate with clay, which generally includes boulders of different sizes. Frequently, several of these varieties of Drift occur together in the same section. By far the greater number of exposures, especially in the uplands, are of Boulder Clay, which consists of rounded, smoothed, and scratched stones enclosed without orderly arrangement in a matrix of clay, generally with an admixture of more or less sand.

The texture of the Drift has had considerable influence upon the

extent to which it has been altered by the action of the weather since its deposition. Tough blue clay, being impervious, weathers to yellow clay for only a little distance below the surface, whereas a sandy clay may be yellow down to 3 or 4 feet or more. On the moorland, the weathered portion of the Drift is usually white or greyish white, owing to the removal of the iron-oxides by the peaty acids in the percolating water.

The texture of the Drift, by determining the extent to which rainwater can percolate through it, has had an important influence upon the apparent distribution of limestone boulders. In nearly every good section of tough impervious Boulder Clay, smoothed and striated Carboniferous Limestone boulders abound, accompanied by angular fragments of Carboniferous chert. In porous Drift and in the weathered portions of Boulder Clay near the surface, limestone-boulders are generally absent, but chert is almost always present. Thus, because of its insolubility and its wide dissemination, chert has proved of great value to the investigator in working out the distribution of the Drift, when the limestone, which was also present originally, has been removed by solution.

(*b*) Constituent Materials.

Most of the materials of which the Drift is composed are such as may be derived either from the rocks below or from those which are, broadly speaking, immediately on the north or west of the deposit. A variable, but generally very small, proportion of the materials does not occur as solid rock within the drainage-area in question. Moreover, in the lowlands the Drift is of a more generalized type, being less dependent upon the nature of the solid rock upon which it rests, and having its matrix more thoroughly ground up than in the uplands, where it includes a greater proportion of local material and approximates more to ordinary rock-waste, the nearer one approaches the upper limit of its distribution.

The matrix of the Boulder Clay, consisting as it does almost entirely of locally-derived material, varies in colour from chocolate-brown and red, where the New Red Sandstone rocks occur, to blue-black where Coal-Measure shales crop out. Numerous sections may be seen where soft rocks pass almost imperceptibly upwards into Drift—the only changes noticeable being the gradual destruction of their stratification, and the presence of occasional boulders of some other rocks which have been ploughed into them.

But for the exceptional occurrence of erratics of large size, the biggest boulders in the Drift consist of local rocks, the far-travelled stones being usually smaller, more rounded, and more frequently striated. Well-striated fragments of black shale and even coal are, however, by no means of rare occurrence.

Three well-marked types of Drift may be distinguished by the boulders which they contain.

The most abundant boulders derived from local rocks are coarse and fine sandstone, shale, coal, and ironstone from the Millstone

Grit and Coal Measures. In a few localities, the sandstone, shale, and impure limestone of the Pendleside Series crop out. Where the Drift contains boulders of the above-mentioned rocks only, it will be termed Local Drift.

When, in addition to the above, boulders of Carboniferous Limestone and chert, and Silurian grit and slate, doubtless chiefly derived from the exposures of such rocks in Ribblesdale and the adjoining parts of the Pennines, occur in the Drift, it will be alluded to as Ribblesdale Drift.

In the most complex type,[1] many rocks from the Lake District and some from the South of Scotland occur, together with any or all of the varieties already mentioned; this type will be termed the North-Western Drift.

It should be understood that each of these three types may include Drift of varying texture.

(c) The Distribution of the Three Types of Drift.

Mr. R. H. Tiddeman[2] first pointed out that in Ribblesdale a boundary might be drawn between the 'Lake-country drift' and the 'local drift,' which is here termed the Ribblesdale Drift.

As the boundaries between the three types of Drift in this part of Lancashire occur for the most part on high moorland that is intersected by many natural and artificial watercourses, it has been found possible to trace them with considerable precision, and on the accompanying map (Pl. XXXIII) they are indicated as reduced from maps on the scale of 6 inches to the mile. The map also summarizes a great many records of boulders and Drift sections throughout the area. The method adopted has been to examine the superficial deposits wherever they are exposed, especially the continuous sections in the gently-sloping channels that have been cut in order to drain the moors. Following such a section up hill, one commonly finds the erratics becoming continuously less abundant until perhaps only two or three occur in a distance of 50 yards, and, farther up the stream, they cease altogether. The general appearance of the Drift, however, remains unaltered in other respects for some considerable distance. Thus, Ribblesdale Drift or

[1] The following list of boulders obtained in Wellington Road, Bury, is given as an example of the variety of rocks that may be found in a single section of North-Western Drift:—Grey granite, probably from Criffel (Scotland). Granites from Shap (Westmorland), found by Mr. H. B. Maufe, and Eskdale (Cumberland). Hornblende-syenite. Granophyre from Buttermere and Ennerdale. Three distinct types of quartz-porphyry. Pink, white, and green varieties of rhyolite. Many types of andesite, one much sheared. Yewdale andesitic breccia. Chalk flints. Limestone breccia with red matrix; probably Brockram. Silurian grit, probably from the Northern Pennines. Greywacke grit, probably from the South of Scotland. Quartzite. Vein-quartz with hæmatite. Carboniferous Limestone with *Lithostrotion* and encrinites. Chert full of casts of large encrinites; banded chert. Millstone Grit. Coal-Measure sandstone and shale; Gannister; coal.

[2] 'On the Evidence for the Ice-Sheet in North Lancashire, &c.' Q. J. G. S. vol. xxviii (1872) p. 485.

North-Western Drift may be seen to pass into Local Drift, the only indication of change being the disappearance of fragments of chert and Silurian grit, or of igneous rocks, as the case may be. The boundary between the Ribblesdale and the North-Western Drifts may be similarly traced by the absence or presence of boulders of gneous rocks.

Sometimes, instead of the proportion of erratics diminishing gradually towards the limit of their distribution, they are particularly abundant immediately below it, and then suddenly disappear from the Drift.

It is obvious that whatever vicissitudes the transporting agents of the Drift may have undergone, the distribution of its three types, as ascertained by the method outlined above, will represent only the last phase of their action. Certain anomalies, however, in the facts of distribution provide us with an occasional glimpse of changes which occurred during the deposition of the Drift prior to the last phase. In order to avoid repetition these will be dealt with in a later section of this paper.[1]

We are not, however, without direct evidence from the Drift itself of alternation in the conditions under which it was distributed. Prof. P. F. Kendall has described[2] sections at Whalley, in which layers of Ribblesdale and North-Western Drift interdigitate one with the other without any mingling of the contents of the different layers. Moreover, in several parts of the Irwell basin, thick masses of Ribblesdale Drift, sometimes containing an occasional boulder of the north-western type, are overlain by typical North-Western Drift with an abundance of fragments of igneous rock. Such instances of the overlap of different types appear, however, to be confined to comparatively low ground, where the Drift has accumulated to a considerable thickness. On the higher ground, where the Drift is thinner, mixing could more easily take place.

(i) The distribution of the Ribblesdale Drift.—North of Boulsworth Hill, the extreme margin of the Ribblesdale Drift crosses the Pennines into Airedale (Yorkshire).[3] The highest altitude to which it has been traced is about 1550 feet above O.D. on the south-west of Boulsworth Hill. Owing to lack of good exposures, the limit has not been exactly determined, although it may be somewhat higher in this locality. The summit of Boulsworth (1700 feet) is driftless.[4]

South of Boulsworth Hill, the Ribblesdale-Drift limit falls, but is traceable up to 1425 feet on the north-east of the Widdop gap,

[1] § IV, pp. 209–12.

[2] See H. Carvill Lewis, 'Glacial Geology of Great Britain, &c.' 1894, pp. 415–16.

[3] A. Jowett & H. B. Maufe, 'Glaciation of the Bradford & Keighley District' Proc. Yorks. Geol. Soc. n. s. vol. xv (1904–1905) p. 212.

[4] W. Gunn, 'Geology of the Burnley Coalfield' Mem. Geol. Surv. 1875, p. 137, & footnote 2, p. 128.

through which it passes into Yorkshire. Good sections of Ribblesdale Drift, with striated boulders, occur on the slopes of the Widdop valley for at least a mile south-east of the Pennine watershed at Widdop Cross. According to the late James Spencer,[1] limestone boulders crossed by this route into Yorkshire, and were scattered over the moorlands down to Wadsworth Moor, nearly 3 miles farther east.

Ribblesdale Drift also extends continuously across the Pennine watershed at the Gorple gap, reaching limits of 1510 feet above O.D. on the hill to the north, and on Black Hameldon to the south of the gap. Excellent sections in the same Drift may be seen for half a mile across the Pennine divide on the north-eastern slopes of Black Hameldon, but the Drift appears to be thinning out eastwards. South of Black Hameldon, the Ribblesdale-Drift limit falls rapidly towards the northern edge of the Cliviger gorge, although on the high ground the Drift forms a thick cover extending for nearly 2 miles to the south-east of the watershed between the basins of the Lancashire and Yorkshire Calders. The sides of the gorge are very steep, and landslips and talus have removed or obscured whatever traces of Drift may have originally existed; but limestone-boulders have been recorded[2] from 18 feet below the floor of the valley at Lineholme, a mile north-west of Todmorden. Blue clay, with chert and big boulders of grit and Gannister, occurs at Hare Hill, over half a mile nearer Todmorden, at 475 feet above O.D. and about 50 feet above the floor of the valley.

On Lower Moor, south of the Cliviger gorge, the limit of the Ribblesdale Drift extends to within less than 2 miles of Todmorden. Its altitude increases westwards to over 1350 feet, diminishing farther west to below 1325 feet, where it crosses the watershed between the basins of the Yorkshire Calder and the Upper Irwell. The Drift-limit does not extend far down the Upper Irwell Valley, terminating about a mile north of Bacup; although in the floor of the valley it may continue a little farther south, under a more recent deposit of gravel and silt. It then crosses the watershed westwards into the Whitewell Brook valley, turning southwards and attaining an altitude of nearly 1300 feet on a westward projecting spur. Farther south its altitude decreases to below 1100 feet north of Stacksteads, where it is crossed abruptly by the northern boundary of the North-Western Drift in the Irwell Valley. The rest of the boundary between the Ribblesdale and the Local Drifts has been obliterated by the deposition of the North-Western Drift.

Within the extreme limit indicated above, the Ribblesdale Drift, on the whole, increases in abundance as one proceeds from its margin towards its source. It is generally thin on the ridges of solid rock, but has accumulated in the hollows except where subsequently removed by stream-action. Thus, it is quite abundant in the upper portion of Green's Clough, 3 miles west-north-west of

[1] 'Erratics of the Calder Valley' Halifax Naturalist, vol. i (1896) p. 48.
[2] *Ibid. loc. cit.*

Todmorden, forming mounds of Boulder Clay full of scratched stones; whereas, on the highest parts of the ridge, from Heald Moor to Deerplay Hill, it is very thin and (in places) practically absent. On the slope immediately south-west of this ridge it becomes much more abundant [1]; but, when traced farther south-westwards towards its limit in the Upper Irwell Valley, it again diminishes in quantity. Moreover, wherever the crest of the ridge is slightly lower, a greater accumulation of Drift is found south of the depression. It would appear, therefore, that this ridge, which attains altitudes of 1419 feet on Heald Moor, 1474 feet on Thieveley Beacon, and 1429 feet on Deerplay Hill, was not far below the limit of the distribution of the Ribblesdale Drift.

West of Deerplay Hill, at the head of the Whitewell-Brook valley, a wide gap occurs in the ridge, which sinks in altitude to 1170 feet. Ribblesdale Drift is abundant in this gap,[2] and in the northern part of the valley on the south it forms morainic mounds. The high ground west of the head of the Whitewell-Brook valley, though nowhere attaining an altitude greater than 1274 feet, has an extremely thin covering of Drift; but, at the head of the Limy-Water valley farther west, great mounds of Drift [3] packed with scratched limestone-boulders occur. Boulders of the Ribblesdale type are also extremely abundant in the Drift south-east of Accrington, in the lower parts of the Limy-Water, Whitewell-Brook and Upper Irwell valleys, and also in the main Irwell Valley south of Haslingden and Rawtenstall.

C. E. De Rance [4] described Drift with erratics, resting upon Till with limestone and other rocks from the Bolland district at Brinscall.

These facts indicate that, but for the masking effect of the North-Western Drift, the Ribblesdale Drift would cover a much wider area than that to which it is now restricted.

(ii) The distribution of the North-Western Drift.—The North-Western Drift covers so extensive an area that it will be more convenient to treat of its distribution in sections, as follows:—

(1) From Great Hameldon eastwards.[5]—The North-Western Drift extends up the western and northern slopes of Great Hameldon, and a single boulder of Lake-District rock has been found on the top (1343 feet); but only Ribblesdale Drift occurs

[1] Mr. H. Bolton, in his 'Geology of Rossendale' 1890, p. 151, states that 'a good thickness of Boulder Clay has been traced over Heald Moor at an altitude of 1419 feet.'

[2] J. Aitken, 'On Drift Deposits on the Western Pennine Slopes, &c.' Trans. Manch. Geol. Soc. vol. xiv (1876–78) p. 51.

[3] J. Kerr, 'Traces of Glacial Phenomena in the Valley of the Irwell & its Tributaries in Rossendale' *ibid.* vol. x (1870–71) p. 116.

[4] 'The Superficial Geology of the Country adjoining the Coasts of South-West Lancashire' Mem. Geol. Surv. 1877, p. 7.

[5] T. T. Wilkinson, 'Drift Deposits near Burnley' Trans. Manch. Geol. Soc. vol. iv (1863–64) p. 110; and E. Hull, 'Geology of the Burnley Coalfield Mem. Geol. Surv. 1875, p. 132.

on the lower ground south-east of the hill. Good sections in the North-Western Drift occur on the northern, and in Ribblesdale Drift on the southern, slopes of the ridge east of Great Hameldon almost up to its crest, which, for about a mile, clearly marks the boundary between the two types. Farther east, the limit of the North-Western Drift falls until reaching the gap at the head of the Limy-Water valley, through which it passes. Small boulders of igneous rocks are found sparingly among the Drift in the upper part of the Limy-Water valley up to about 925 feet, above which Ribblesdale Drift only occurs.

Along the hillside south of Burnley, Lake-District rocks are quite abundant near the limit of their distribution, which falls gradually eastwards and then rapidly south-eastwards towards the entrance to the Cliviger gorge. A clear boundary has been traced along the western slopes of the Pennines south-east and east of Burnley, at altitudes up to 1050 feet O.D.; other records [1] serve to continue it north-eastwards, until it crosses the Pennines into Airedale.

(2) From Great Hameldon to the Walsden gorge.—Immediately south of Great Hameldon, the Drift includes a few scattered boulders of Lake District rocks, which for nearly 2 miles are found only on the west of the ridge from Great Hameldon to Cribden, the ridge itself and its eastern slopes being covered by Ribblesdale Drift. Farther south igneous rocks are found across the ridge, and become increasingly numerous along it—many occurring around Cribden,[2] and a few on its summit (1317 feet above O.D.).

South of Cribden the Irwell Valley extends eastwards towards Bacup, and the North-Western Drift is abundant [3] all the way, rising to high altitudes on the north, east, and south of the Rossendale basin. On the ridge east of the Limy-Water valley, it reaches a northern limit at 1075 feet above O.D., towards which the Lake-District boulders diminish in number and in size. Farther north this ridge is scantily covered by Ribblesdale Drift.

South-west of the high ground east of the Whitewell-Brook valley, the North-Western Drift does not extend so far northwards, nor does it attain so great an altitude as farther east on the hill-slopes around Bacup. Moreover, from this point, the Ribblesdale and North-Western Drifts are no longer in contact, the latter extending beyond the area occupied by the former, and passing at high levels into Local Drift.

[1] A. Wilmore, Trans. Burnley Lit. & Sci. Soc. vol. xv (pub. 1900) p. 58; *id.* 'Glacial Geology of Colne & District' Proc. Colne Lit. Sci. Soc. 1908, p. 17; and A. Jowett & H. B. Maufe, Proc. Yorks. Geol. Soc. n. s. vol. xv (1904–1905) p. 200.

[2] J. Aitken, 'On the Occurrence of High-Level Drift in the Neighbourhood of Bacup' Trans. Manch. Geol. Soc. vol. xiii (1874–76) p. 137.

[3] J. Aitken, Trans. Manch. Geol. Soc. vol. xiii (1874–76) pp. 134, 137; J. Kerr, *ibid.* vol. x (1870–71) p. 117; H. Bolton, 'Geology of Rossendale' 1890, pp. 139–52; and *id.*, 'On the Finding of Marine Shells in the Boulder Clay of Bacup' Trans. Manch. Geol. Soc. vol. xxi (1892) p. 574.

Along the south side of the Irwell Valley, from Rawtenstall to Bacup, the limit of the North-Western Drift can be traced continuously; and, precisely as on the north of the valley, after falling at first, it again reaches higher altitudes farther east.

Near Rawtenstall, the Irwell bends south-westwards and then southwards, flowing through a deep narrow valley that opens out upon the South Lancashire plain at Bury. In this valley the North-Western Drift is very abundant, reaching a limit which, on the whole, becomes gradually lower southwards until it makes a sudden bend towards the east, passing along the southern slopes of the Rossendale highland, where it attains a much higher altitude. Lake-District rocks occur near the top of Knowl Hill (over 1350 feet), and reach a limit on the moorland farther north at about 1325 feet above O.D. On the next southward projecting spur farther east, two boulders of andesite were found at an altitude of about 1385 feet. From this point the North-Western Drift-limit turns north-eastwards and then northwards to rejoin that in the Irwell Valley south of Bacup, gradually diminishing in altitude northwards. A similarly northward decrease in altitude of the limit of the North-Western Drift may be traced on the high moorland north-east of the Whitworth valley. Reaching a maximum of over 1400 feet north-east of Whitworth, it falls to 1240 feet on the watershed between the Whitworth and the Upper Irwell valleys, and to 1160 feet east of Bacup. It is noteworthy that boulders of igneous rocks (particularly Buttermere granophyre) are very abundant and of large size in the Whitworth valley[1] up to and just over the watershed to the north, and also occur high up towards the Drift-boundary in the Upper Irwell Valley, whereas they are smaller and less numerous in the Drift on the lower slopes of the Upper Irwell Valley. On the other hand, there is a greater admixture of boulders of the Ribblesdale type in the Drift of the Irwell Valley and a paucity of such boulders in the upper part of the Whitworth valley. Thus one can hardly escape the conclusion that the North-Western Drift of the Whitworth valley and of the higher parts of the Upper Irwell Valley differs markedly in its boulder contents from the North-Western Drift of the Upper Irwell Valley at lower levels, the latter being similar to that in the Irwell Valley farther west. In fact, a band of mixed North-Western and Ribblesdale Drift might be mapped in the valley of the Irwell and its tributaries from near Accrington to Bacup and Bury, but for the impossibility of drawing a definite boundary on the west and south, in which directions the mixed type, so rich in Ribblesdale Drift, passes insensibly into the true North-Western Drift.

After crossing the watershed east of the Whitworth valley at about 1400 feet above O.D., the North-Western Drift-limit falls eastwards towards the southern entrance of the Walsden gorge, terminating on the gentler slopes at the brink of the gorge, a

[1] S. S. Platt, 'Some of the Recent Results of the Investigations into Local Erratic Blocks' Trans. Rochdale Lit. Sci. Soc. 1892.

quarter of a mile north of the actual watershed between the Irwell and Calder basins, at an altitude of 925 feet above O.D.

Along the western slopes of the Pennines, the limit of the North-Western Drift attains a maximum altitude of 1375 feet west of Blackstone Edge, and falls northwards and north-westwards to the eastern edge of the Walsden gorge.[1] The way in which the limits of the North-Western Drift terminate opposite to each other on the gentler slopes above the gorge is very striking, especially as nowhere in the whole area can the passage of North-Western into Local Drift be more clearly demonstrated than in this neighbourhood, the erratics being numerous and of moderate size close to the limit of their distribution.

Boulders of igneous rocks have been recorded from several localities in the Walsden gorge, as far as Todmorden and all down the Calder Valley[2]; but the deposit of tough blue clay with big striated boulders of the North-Western type found at Millwood (Todmorden gasworks) is of greatest significance[3] for our purpose.

[My own mapping of the Drift was not carried more than a mile or two south of Blackstone edge. The following statement by the late C. E. De Rance with reference to the district farther south has an important bearing upon the general problem :—

'Fragments of sea-shells [occur] up to 1280 feet and granites from the South-West of Scotland and 7-foot boulders of andesites from the Lake District at 1330 feet. Westward of the Pennine Axis the Glacial Drift rises to [the 1250-foot contour] or somewhat above it in both Lancashire and Cheshire; eastward, though lower elevations may occur, the Drift is conspicuous by its absence.' (Trans. Manch. Geol. Soc. vol. xxii, 1892–93, p. 51.)]

(3) Winter Hill.—The hill-country west[4] of the Irwell Valley is everywhere covered by North-Western Drift, with the exception of its highest point, Winter Hill,[5] north of Bolton. North-Western Drift occurs up to over 1460 feet on the north-west of this hill, and its maximum altitude diminishes on both sides of the hill towards the south-east, where it extends only to about 1300 feet above O.D.

(iii) The distribution of the Local Drift.—It has been shown above how the foreign Drift passes insensibly into Drift in

[1] E. W. Binney, 'Additional Notes on the Lancashire Drift Deposits' Proc. Manchester Lit. & Phil. Soc. vol. xi (1872) p. 139; R. Law, in report on 'Erratic Blocks of the British Isles' Proc. Brit. Assoc. (Liverpool) 1896, p. 371.

[2] J. W. Davis, 'Erratic Boulders in the Valley of the Calder' Proc. Yorks. Geol. Soc. vol. vi (1875–79) pp. 93–98; J. Aitken, 'Drift Deposits on the Western Pennine Slopes, &c.' Trans. Manch. Geol. Soc. vol. xiv (1876–78) pp. 51–56; and R. Law & W. Simpson, 'Report on the Drift Deposits at Mytholmroyd' Proc. Yorks. Geol. Soc. n. s. vol. xiv (1901) pp. 231–36.

[3] J. Spencer, 'Halifax Naturalist' vol. i (1896) pp. 21–25 & 45–49.

[4] J. Aitken, 'An Outlier of Drift-Gravel on Holcombe Hill' Trans. Manch. Geol. Soc. vol. vii (1868) p. 57; 'High-Level Drift in the Neighbourhood of Bacup' *ibid.* vol. xiii (1874–76) p. 135.

[5] E. Hull, 'The Geology of the Country around Bolton-le-Moors (Lancs.)' Mem. Geol. Surv. 1862, p. 29.

which only boulders of local rocks occur. As one proceeds farther away from the limit up to which erratics occur, the boulders of local rocks are less rounded, and cease to include different types: the matrix becomes more like a pulverized mass of the solid rock immediately below; and so the Local Drift passes gradually into ordinary undisturbed subsoil.

The only region within the scope of this enquiry in which the subsoil is clearly undisturbed and Drift entirely absent, lies to the south-west of Todmorden. Here the highest parts of the hills and their north-eastern slopes appear to be devoid of Drift.

A considerable Driftless area also occurs east of Boulsworth and Black Hameldon.

III. Evidences of Ice-action.

In addition to the testimony furnished by the Drift with its smoothed and striated boulders, and the orderly distribution of its erratics, abundant evidence exists in support of the view that there was once an ice-sheet in East Lancashire. Except where the surface has been disturbed by recent weather and stream-action and by landslips, its contours are everywhere rounded and smoothed. The Drift varies in thickness, often levelling the surface by filling up hollows and accumulating upon the slopes of the hills; but the hilltops and outstanding ridges are usually either bare, or have a very thin covering of Drift.

In the larger valleys and upon the plains Drift is abundant, frequently presenting characteristic morainic outlines. Numerous mounds occur at the Burnley entrance to the Cliviger gorge, some of which are composed partly of solid rock and partly of Drift; but these are smoothed and rounded, so that only an occasional section reveals their composite character.

The finest series of morainic mounds in the district covers a large area on the south of the Rossendale highland, stretching from Bolton to Bury, Rochdale, Middleton, and North Manchester.

Throughout the whole Drift-covered area, the details of the present drainage-system are due to the blocking of the pre-existing valleys by great mounds of Drift. Lakes were thus produced that have been partly converted into alluvial plains, across which the present streams meander, and partly drained by way of the gorges that have been cut by the streams through the obstructions. These gorges are sometimes cut in Drift and sometimes in the solid rock, the abundance of potholes and other evidences of recent and continuing rapid erosion bearing ample testimony that the processes of readjustment are not yet complete.

The positions of the several striated rock-surfaces[1] are indicated

[1] C. E. De Rance, 'Superficial Geology of the Country adjoining the Coasts of South-West Lancashire' Mem. Geol. Surv. 1877, p. 47; R. H. Tiddeman, Q. J. G. S. vol. xxviii (1872) pp. 489–90; and H. Carvill Lewis, 'Glacial Geology of Great Britain, &c.' 1894, p. 269. Mr. H. B. Maufe discovered a striated surface at Rowlands, Summerseat (south of Ramsbottom), in 1901: altitude, 450 feet; direction, north to south.

on the map (Pl. XXXIII) by arrows marking the direction of the scratches. Their number, is, however, disappointingly small, owing to the fact that, where good striæ might be expected, the surface of the rock is often rubbly and broken into fragments, or the Drift-cover has been too thin to protect the rock-surface from subsequent denudation by atmospheric agencies. Moreover, the area does not appear to have been subjected to vigorous glaciation.[1]

There are numerous examples of 'terminal curvature' due to the ploughing action[2] which goes on at the base of an ice-sheet. In the preparation of a list[3] of especially good instances of this phenomenon, care has been taken to eliminate sources of error, due to the possible effects of landslip and soil-creep, by recording examples in which the disturbing influence has clearly acted up hill. It is also noteworthy that, although these examples yield no such exact record of the direction of ice-movement as can be obtained from clear scratches on undisturbed rock, their evidence is never in opposition to the rest of the evidence from which the directions of ice-movement are inferred, and is therefore of great positive value in supporting the latter.

In close relationship with the evidence derived from striæ and terminal curvature, is the uplift of boulders of local rocks. Most of the hills making up the Rossendale highland are capped by Coal-Measure rocks, Millstone Grit cropping out at lower levels on the hillsides. The occurrence of boulders of Millstone Grit on high ground consisting of Coal-Measure rocks is therefore good evidence of uplift by the distributing agent, in some cases to the extent of at least 200 feet.

Further evidence of the existence of an ice-sheet is furnished by the succession of valleys, trenching the hillsides parallel with the contours and cutting across spur after spur, which can only be satisfactorily explained by reference to a fluctuating barrier such as an ice-sheet would provide.

IV. Inferences respecting the Ice-Sheet and its Movements.

The evidence already examined points to the general conclusion that East Lancashire was invaded by two streams of ice, one from Ribblesdale flowing southwards between Pendle and Boulsworth Hills, and a much larger stream flowing south-eastwards, passing over the western part of the Rossendale highland, inundating the plain on the south of this ridge, and reaching high up the western slopes of the Pennines at Blackstone Edge. The fusion of these two streams into a great ice-sheet in North

[1] See p. 210.

[2] R. H. Tiddeman, Q. J. G. S. vol. xxviii (1872) pp. 482–83; and J. Eccles, 'Superficial Curvature of Inclined Strata near Blackburn' Trans. Manch. Geol. Soc. vol. vii (1867–68) p. 20.

[3] See Appendix, p. 227, and the broken arrows on the map (Pl. XXXIII).

Lancashire was postulated by Mr. R. H. Tiddeman,[1] who pointed out the diversion of the ice-drainage of the Lune and Ribble basins consequent upon the obstruction of its natural outlet by the ice from the Lake District. The Ribblesdale ice thus had a tendency to escape eastwards across the Pennines wherever suitable gaps presented themselves; and we find, in addition to the great flow of ice into Airedale, north of Boulsworth Hill, small ice-lobes crossing the watershed at Widdop and at Gorple and a larger stream flowing into Upper Calderdale. It is worthy of note that there is, broadly speaking, a gradual decrease in height of the Drift-limits marked on the map as one proceeds in the direction in which the Drift was carried, a fact which is in itself a strong argument in support of the glacial origin of the Drift.

A detailed examination of the Drift-limits in their relation to the surface-features will reveal many illustrations of the general principle[2] that obstacles in the path of an ice-stream tend to retard its movement and to limit its extension, the level of the ice being usually raised higher in front of an obstacle and depressed on its lee side. The best examples occur in the Upper Irwell basin, as its hills are high enough never to have been deeply covered, even when the ice attained its maximum thickness. The complementary principle that deep narrow valleys tend to control and direct the movements of the ice within their confines is also well illustrated, and for the same reason—although there is good evidence that, when the ice was of sufficient thickness, its upper layers moved along in the general direction of ice-movement, shearing over the more restricted currents below. It is clear, however, that in this area we are recording conditions which hampered the movements of the ice so much that its chief function was deposition, erosion being reduced to a minimum.

The high ground north and north-east of Bacup was crossed by the Ribblesdale ice, though apparently never in sufficient quantity to give rise to a strong southward-moving stream. Lower gaps, however, occur on the west, and through them definite streams of Ribblesdale ice flowed down the Whitewell-Brook and Limy-Water valleys. Along with this southward to south-westward flow of the Ribblesdale ice there was a movement of the North-Western ice along the valley from Accrington to Burnley, as shown by the gradual fall of the North-Western Drift-limit along the steep northward slope of the ridge from Great Hameldon eastwards. The North-Western ice appears to have crossed this ridge only as a small lobe through the gap at the head of the Limy-Water valley, though a few boulders of igneous rocks have been found in the Ribblesdale Drift in the Whitewell-Brook valley, and a small isolated patch of North-Western Drift occurs at 1350 feet above O.D. on the watershed between the Whitewell-Brook and Upper Irwell valleys.

[1] Q. J. G. S. vol. xxviii (1872) p. 487.

[2] P. F. Kendall, 'Supplementary Observations on the Glacier Lakes of Cleveland' Proc. Yorks. Geol. Soc. n. s. vol. xv (1903) p. 43.

A consistent explanation of the whole of these facts is by no means easy to devise. If we regard the region east of Great Hameldon alone, the distribution of the Drift clearly shows that the Ribblesdale ice everywhere extended beyond the extreme limits reached by the North-Western ice. Moreover, had the North-Western Drift been deposited first, the Ribblesdale ice could hardly have passed over it without destroying the North-Western Drift boundary, and incorporating within itself a sufficient number of north-western boulders for the deposited Drift to be of the north-western type. Instead of this, boulders of the north-western type are markedly absent from the Ribblesdale Drift. Yet, as already urged, the movements of the Ribblesdale ice farther east clearly point to the simultaneous existence of a barrier on the west; they are certainly not consistent with a complete retreat of the Ribblesdale ice, leaving the North-Western ice in possession of the field when it attained its greatest development. These considerations have led me to put forward the following hypothesis.

The Ribblesdale ice advanced first, and spread its drift far beyond the present limited area over which it occurs. The North-Western ice then pressed up the valley between the Pendle chain and the Rossendale highland as an undercurrent, practically not mixing with the Ribblesdale ice, which would be raised above it after the manner of a laccolite. The isolated portion of North-Western Drift mentioned above might have been caught up by the Ribblesdale ice, as it sheared over the underlying North-Western ice, carried bodily along, and deposited within the area now covered by Ribblesdale Drift. The advance of the North-Western ice up the valley, by interposing a barrier where the Ribblesdale ice had previously been free to move, would so tend to cut off the supply of Ribblesdale ice in this locality that, when at its maximum extension, the North-Western ice would only have a thin covering of Ribblesdale ice, which would be practically stagnant and would leave almost unfettered the movements of the more powerful stream from the west. This is suggested by the shape of the North-Western Drift-limit, which, especially in the vicinity of Great Hameldon, clearly indicates that the Drift was deposited by ice pressing in from the north-west. The distribution of the Drift suggests that, while the valleys of the Limy Water and Whitewell Brook were filled with Ribblesdale ice, the North-Western ice pushed over the ridge south of Great Hameldon, and flowed directly across the surface of the Ribblesdale ice contained in the two valleys, and over the southern portion of the ridge between them. The main portion of the same stream of North-Western ice flowed eastwards up the Irwell Valley from Rawtenstall to Bacup, its surface, as indicated by the margin of the Drift, falling steadily in that direction towards the narrowest part of the valley immediately east of Waterfoot. South of Rawtenstall, the deep Irwell Valley controlled a large southward-flowing stream, the hills on the west reducing the pressure from that direction and preventing the

North-Western ice from extending very high up the eastern side of the valley.

The South Lancashire and Cheshire plain on the south of the Rossendale highland presented no obstacle to the North-Western ice, which consequently attained a greater thickness along the western slopes of the Pennines here than farther north.

Although a great quantity of ice flowed southwards over the comparatively-low ground between the Welsh hills and the Pennines, the supply was sufficient to maintain a mass of ice over 1000 feet thick between the Rossendale highland and the Pennines. It is also probable that the North-Welsh ice, though never directly invading this area, had, by exerting a pressure from the south-west, an important indirect effect in raising the level of the ice-surface in South Lancashire, and thus assisting a tendency to a northward and north-eastward movement. The barrier interposed by the Rossendale hills and by the ice from the north-west had effectively stopped the further progress of the Ribblesdale ice, and even the stream of North-Western ice which crossed the western portion of the Rossendale highland must have been weakened thereby. Thus, at the time of maximum glaciation, there was little to oppose the extension of the comparatively-stagnant ice between the Rossendale highland and the Pennines towards the north and north-east, and possibly a slight reversal of flow took place where the valleys that were occupied by ice opened out upon the plain. It would appear, however, that the height attained by the composite ice-sheet north of the Rossendale highland was greater than the height reached by the ice on the south throughout the whole period of glaciation. In the case of the Whitworth valley, which was unobstructed, a definite flow northwards occurred, the ice passing over the watershed, spreading over the surface of the ice which had already entered the Upper Irwell Valley from the west, and possibly producing a slight tendency towards a westward movement, the balance between the two ice-streams occurring where the Irwell Valley narrows east of Waterfoot. The influence of ice-pressure from the west, as well as from the south, in the Whitworth valley is indicated by the general higher altitude attained by the North-Western Drift on the eastern than on the western side of the valley. A similar northward-flowing stream passed through the Walsden gorge, and entered the basin of the Yorkshire Calder.[1]

Hence, although the greater part of the area here dealt with was covered by a confluent ice-sheet, the irregular mass of hills and valleys in East Lancashire produced upon the ice an effect on a much larger scale than, but otherwise similar to, that due to a number of big boulders slightly submerged in a river; the surface of the ice was probably diversified with ridges and hollows, and various eddies were produced within the body of the ice. Over the South Lancashire plain, however, the ice-surface was doubtless more uniform.

[1] J. Spencer, 'Halifax Naturalist' vol. i (1896) p. 21.

Origin of the Local Drift.

Owing to its limited extent, and to the fact that its boulders consist of rocks similar to those upon which it rests, the Local Drift furnishes far less evidence of the direction of ice-movement than the other two types. That it is due to the action of the same ice as that which deposited the foreign Drift is evident from the following considerations:—

(1) At the junction between the two, the foreign Drift passes insensibly into Local Drift similar to it in every way, but for the absence of far-travelled stones. Thus the Local Drift forms a belt intervening between the foreign Drift and the unglaciated area.

(2) Wherever any evidence is obtainable from its boulders, as for example, where boulders of Millstone Grit are found in Drift resting upon Coal-Measure shale, the direction in which they have travelled is always in agreement with the direction of ice-movement deduced from evidence obtained within the area covered by the foreign Drift.

(3) There is a similar agreement where the direction of ice-movement is indicated by the disturbance of the underlying solid rock, of which good examples occur within the area covered by Local Drift.

These phenomena are attributable to the action of the clean ice[1] which no doubt existed at the surface of the ice-sheet (see section, p. 214). This upper layer of clean ice would become charged, where in contact with the ground, with local rock-débris; and, as the ice-sheet gradually spread farther, more débris would be picked up by a new portion of clean ice, the previous local débris being mixed with erratics by the further extension of the lower layers of ice. This would continue until the ice-sheet attained its maximum development, the Local Drift now remaining having been produced, at that stage only, by the clean ice which extended beyond the limits of the underlying ice containing foreign Drift. Moreover, the Local Drift would, on this assumption, be best developed near the margin of the foreign Drift, for here the ice-bearing Local Drift would be thickest, and therefore the boulders within it would be subjected to more severe glaciation for a longer time than those nearer the edge of the ice-sheet. In no case would the Local Drift be transported far; the materials of which it is composed would be originally much weathered, as the thin ice would not have much erosive action on the rocks below,[2] and consequently the boulders are not likely to be striated. All this is in agreement with the facts actually observed.

[1] P. F. Kendall, in G. F. Wright's 'Man & the Glacial Period' 1892, p. 166; and G. W. Lamplugh, 'Geology of the Isle of Man' Mem. Geol. Surv. 1903, pp. 393 & 394.

[2] An interesting example illustrating this point may be cited from the eastern slopes of Black Hameldon. Undisturbed subsoil and more finely-divided material, apparently produced by ordinary weathering from the grit and shale upon which they rest, are covered by from 6 inches to a foot of Drift with rounded stones (in one case with chert also). Here not only was the ice thin and near its extreme limit, but the soil and subsoil over which it passed were probably frozen hard and so preserved intact.

Diagram illustrating the formation of a strip of Local Drift at the margin of the glaciated area.

The Thickness of the Ice-Sheet.

The extent of the Local Drift suggests that the upper layer of clean ice was from 200 to 300 feet thick, whence we may infer that the actual surface of the ice-sheet at Winter Hill probably reached an altitude of 1750 feet above O.D.

From the maximum altitudes attained by the North-Western Drift, from Winter Hill to the Pennines, the surface of the ice-sheet has been estimated to have fallen eastwards between 4 and 5 feet in a mile. Hence, assuming this gradient to be continued westwards to the middle of the Irish Sea, the altitude of the surface of the ice-sheet would be there approximately 2100 feet above present sea-level, in the latitude of Winter Hill, at the culmination of the Glacial Period.

V. Systems of Glacial Drainage.

Prof. Hull[1] described several watersheds in this region as occurring in valleys, and called attention to the fact that these valleys were generally broad and level. The Walsden gorge . . .

'is one of the deepest and most perfectly formed valleys in Lancashire.... The change of inclination in the ground on crossing the saddle is almost imperceptible to the eye, and the bottom of the valley presents a smooth surface, which, though not at present containing any stream, has clearly been levelled by the action of water.'

In his memoir on the Glacier Lakes of Cleveland,[2] Prof. P. F. Kendall expounded the principles underlying such phenomena, and examples have been recognized in various parts of the British Isles, but in few areas are they better developed than in East Lancashire.

Among the dominating features that acted as controlling factors of the drainage, at different stages during the retreat of the ice and in different parts of this area, the great Walsden gorge is the most important. The altitude of its floor on the watershed between the North Sea and the Irish Sea is about 610 feet above O.D., and on the western side of the watershed are many drainage-channels above that altitude which were, one after another, tributary to the Walsden Gorge as the ice-barrier decreased in height. Broadly speaking, the area drained by this gorge ultimately included the whole of the Irwell basin that was not covered by ice, up to the time when the ice-barrier in the Roch Valley fell below 600 feet above O.D., together with a number of small areas at the heads of valleys on the northern side of Rossendale, the drainage of which was reversed so as to enter the Irwell basin instead of that of the Ribble.

The feature next in importance is the Cliviger gorge, between Burnley and Todmorden. Towards it are directed a number of drainage-channels south of Boulsworth Hill, indicating that it

[1] 'Geology of the Burnley Coalfield' Mem. Geol. Surv. 1875, pp. 6–8.
[2] Q. J. G. S. vol. lviii (1902) pp. 471–569.

continued to operate until the ice-barrier in the neighbourhood of Burnley sank below 775 feet above O.D., the lowest altitude of the watershed in the gorge.

The third great feature is represented by a series of deep channels between the Rossendale highland and the Irish Sea. Their position and magnitude indicate that, after the Cliviger overflow-channel was abandoned, and before the natural outlet of the Ribble was unsealed, they conveyed the surplus drainage of Ribblesdale into the Irwell-Mersey basin.

There were thus two great episodes in the history of the glacial drainage in this area. During the first, the western drainage crossed the Pennine watershed by the Cliviger and Walsden overflow-channels into Calderdale; and during the second, it was entirely disposed of west of the Pennines.

It has been shown that, at the culmination of the Glacial Period, this region was practically all ice-covered up to, and generally across, the Pennine watershed. The development of extensive systems of glacier-lakes and overflows could therefore only take place during the advance of the ice-barriers towards their maximum extension, and after the ice had retreated sufficiently to expose a certain amount of land-surface sloping towards the ice-barrier. Consequently, we fail to note here the close connexion between the margin of the Drift and the complete series of lakes and overflow valleys that is found where considerable unglaciated areas projected above the surface of the ice-sheet at its maximum extension.

The most obvious condition that a number of overflow-channels must satisfy, in order to be considered as being in operation at the same time and thus marking the position of the ice-barrier at a particular stage, is an unbroken decrease of altitude from the highest to the lowest. In the same direction there should also be a gradual increase in the capacity of each channel, as measured by the area of its cross-section on the watershed through which it cuts—because each lake had to pass on to the next, not only the water that it received from the preceding lake, but also the surplus drainage of its own basin. Moreover, as the ice-sheet retreated, the increase in the amount of water draining from the land as a result of the increased area not covered by ice naturally tended to make the overflow-channels at lower altitudes greater than those at higher altitudes, *cæteris paribus*. In some cases, however, instead of a single overflow-channel between two others, two or more may occur near together, their altitudes lying between the two extremes, and their joint capacities also being intermediate between those of the overflows next above and next below in the sequence.

The overflow-channels on the south and west of the Rossendale highland fulfil these theoretical requirements to a remarkable degree, the distance between one 'aligned sequence' and the next being generally sufficient to separate them completely, and thus, with few exceptions, leaving no doubt as to the set to which any particular channel belongs.

The important corollary follows immediately that, in this locality, the ice-barrier must have been withdrawn very uniformly, and that the chief pauses that may have occurred during its retreat were not merely local, but affected a considerable area.

It is perhaps unnecessary to state that the connexion between the overflow-channels in an aligned series is usually made through lakes held up by the ice-barrier, although the occurrence of scarped hillsides between one channel and the next, or between two lakes, indicates that the connecting-link was sometimes a channel between the ice-edge and the hill-slope against which it was resting.

(*a*) The Cliviger Series of Lakes and Overflow-Channels.

The glacial drainage-channels that cross the Pennines north of Boulsworth Hill have been already described,[1] and Dr. A. Wilmore has dealt with some that occur in the Burnley and Colne area.[2]

A few examples of glacial drainage-channels have been found east of the Pennine watershed in this area. Two occur on Todmorden Lower Moor above the Cliviger gorge, about 1 mile south-east of Portsmouth; they do not actually cut through the ridge, but notch its south-eastern slope. Probably the first glacier-lake to be formed in this region was dammed up in a small valley (Paul Clough) opening into the Cliviger gorge about a mile north-east of Portsmouth. It overflowed south-eastwards through what is now a dry gap, at 1000 feet above O.D. With the exception of one or two valleys of doubtful origin, there are no other overflow-channels in the Cliviger gorge south-east of the watershed.

Whinberry Flat, about three-quarters of a mile south-east of the Gorple gap, is a mass of alluvium which probably occupied the site of a glacier-lake formed when the ice stood at about 1300 feet. The lake had as its outlet a shallow channel directed eastwards.

Several small overflow-valleys were formed by the direct drainage from the edge of the ice, as soon as it retreated to the west of the watershed: one cuts through solid rock at about 1285 feet on the south-western side of the wide col at Widdop Cross, and two parallel channels are cut through the Drift that covers the watershed at the Gorple gap, at about 1275 and 1250 feet above sea-level respectively.

As soon as the ice retreated west of the Pennines a lake was probably formed at the head of Shedden Clough (west of Black Hameldon). Its waters escaped southwards through a shallow notch, just below 1275 feet O.D., in the ridge between Shedden Clough and the Cliviger valley. Farther west, this ridge is cut by several very characteristic overflow-channels, all draining southwards, and is also frequently scarped where water escaped between the ice

[1] A. Jowett & H. B. Maufe, Proc. Yorks. Geol. Soc. n. s. vol. xv (1904–1905) pp. 227 & 228.

[2] 'Glacial Geology of Colne & District' Proc. Colne Lit. Sci. Soc. 1908, pp. 17–20.

and the ridge. The highest quite unmistakable overflow-channel is about 30 feet deep, on the watershed at the head of Catridge Clough. The floor of the channel south-east of the ridge consists of Boulder Clay, exposed in section by the small stream that here takes its rise. The course of the present stream is much steeper than that of the overflow-channel, the latter having suffered considerably from post-Glacial denudation. It should be noted that, while this overflow-channel was in use, the Cliviger gorge on the south-west, or as much of it as existed at this stage, must have been full of ice. The altitude at which the Catridge channel began (1160 feet) corresponds with that of a delta-like feature below the highest channel which cuts through the ridge between Hurstwood Brook and Swinden, so that at this stage a lake probably occupied the upper reaches of Shedden Clough, Cant Clough, and the valley of Hurstwood Brook. At the same time, a lake at a higher level (1200 feet) occupied the head of Swinden, and received the waters of still another lake in Thursden, the waters of which were at a level of about 1260 feet. This lake was formed when the ice retreated from the watershed at Widdop Cross. The highest overflow-channel across the ridge south of Thursden is dry on the watershed; but, lower down, a small stream has exposed an excellent section in well-stratified material, consisting chiefly of shale with layers containing grit-boulders and sand and a few pieces of chert. This is evidently the delta of the stream which flowed into the Swinden lake, for its upper surface slopes gently from about 1225 to 1200 feet, an altitude corresponding with that of the highest overflow on the next ridge to the south. We thus have evidence for a chain of lakes, connected by overflow-channels from Thursden to Catridge Clough, which conveyed the drainage of the western slopes of the Pennines south of Boulsworth Hill into the basin of the Yorkshire Calder. As the ice-barrier retreated, gap after gap was cut at lower altitudes through the ridges between the lakes; the levels of the water in the lakes were lowered; and the lakes increased in area, the drainage finding its way ultimately across the watershed by way of the Cliviger gorge into the Yorkshire Calder.

Although space forbids a detailed account of all these overflow-channels, some of which are fine examples with deltas at their lower ends, the Cliviger gorge itself must be dealt with. This valley is 400 feet deep on the watershed, where, according to Prof. Hull,[1] it is filled with Drift. Landslips, by breaking away from the sides and filling the floor of the gorge, doubtless account for the absence of the characteristic outlines of a Glacial overflow-valley on the watershed: for, although a valley certainly existed here before Glacial times, it must have been further ground out by the ice, as well as deepened by the water, that passed through it during the advance and retreat of the ice-barrier. The floor of the gorge

[1] 'Geology of the Burnley Coalfield' Mem. Geol. Surv. 1875, p. 7.

south-east of the watershed has also been much altered by torrential waters, which have obstructed it with ridges of detritus derived from its precipitous sides since it ceased to be an overflow-channel. Plains of alluvium occur above these mounds, and the diminutive Calder has cut its way through the latter, forming small gorges.

The watershed in the Cliviger gorge is now just below 775 feet, but it may have been somewhat lower before the landslips mentioned above. The last overflow-valley on the ridge to the north also cuts below 775 feet, from which we may infer that the union of the great lake north of this ridge with the lake in the Cliviger valley north-west of the watershed took place about the time when the Cliviger gorge ceased to operate as an overflow-channel. The abandonment of the Cliviger gorge could only result from the opening of some other outlet for the water at a lower level than the watershed at Calder Head. Now, all the overflow-channels mentioned above indicate a gradual fall of the ice-barrier southwards, which suggests that there was an effective, though diminishing, pressure of ice from north to south in this locality, and presupposes an ice-stream between the Pendle chain and the Pennines, extending southwards as far as Hurstwood, when the Cliviger overflow ceased to operate. This being the case, there was no possible means of escape for the waters of these lakes below 775 feet across the Pennines towards the north. Nor does any gap exist across the main watershed of the Rossendale highland below that altitude, until we come to the Brinscall gap 4 miles north-east of Chorley. It is, therefore, practically certain that the retreat of the ice-barrier, by allowing the water impounded in the Cliviger valley above Burnley to escape through the Brinscall gap, led to the abandonment of the Cliviger overflow. This also marks the time of definite separation between the ice-stream from the north and that from the west, for now a lake existed in the basin of the Lancashire Calder, extending, broadly speaking, from Blackburn to Burnley, and confined between two ice-barriers, one a short distance west of Blackburn, and the other at Burnley.

The gap in the Pendle chain at Whalley is not an important factor in the existence of this lake, for it was doubtless obstructed by ice in the Ribble Valley at this stage; and, even if this were not the case, the ice that acted as a barrier between the Pendle chain and the Rossendale highland west of Blackburn must have been still higher at the outlet of the main valley of the Ribble farther north; hence, so long as the North-Western ice formed an effective barrier here, any drainage from the Ribble basin could not have escaped northwards by way of the Whalley gap, but must necessarily have ultimately escaped southwards by the overflow-channels west of the Rossendale highland. It was only when the main Ribble Valley was unsealed, that the drainage of the Lancashire Calder could escape by the Whalley gap into the Ribble.

(*b*) The Walsden Series.

At a very early stage, when an ice-lobe occupied the Walsden valley, a small lake existed in the Upper Irwell Valley, and probably drained directly into the Calder basin through the gap at Sharney Ford near Bacup. It overflowed later across the ridge into a small lake at the head of the Wardle valley, which may have first discharged across the watershed on the north-east.

As soon as the entrance of the Walsden gorge was exposed by the south-westward retreat of the ice in the valley of the Roch, other glacier-lakes began to form at the heads of the valleys on the south of the Rossendale highland and on the west of the Pennines. The channels cut by the overflow from these lakes are directed eastwards and northwards respectively towards the Walsden gorge.

There are four well-defined stages of retreat of the ice-barrier from the hills north of the Roch Valley—during which the drainage was directed eastwards, and crossed the Pennines by way of the Walsden gorge.

The retreat of the ice south of Shore Moor provided a new outlet for the Wardle lake, and a series of channels was cut, which drained eastwards before the entrance to the Walsden gorge was entirely ice-free.

During the next stage, a series of large channels was formed, the last of which cut down nearly to 800 feet close to the entrance to the Walsden channel. A small lake in Naden Dean overflowed into a large lake that extended across the watershed in the Whitworth and Upper Irwell valleys, the surplus water from which passed into the Wardle lake and so into the Walsden channel.

The third stage is rather more complicated. When the ice-barrier retreated sufficiently to expose the wide gap south-west of Brown Wardle Hill, the Whitworth lake would fall rapidly to below 1000 feet, the overflow taking place eastwards into the Wardle lake. This necessarily led to the separation between the Upper Irwell lake and the Whitworth lake, as the watershed between them stood at an altitude of 1050 feet. Water from the Irwell lake continued to escape southwards across the watershed into the Whitworth lake, cutting a channel, now dry, below 1000 feet; and the Whitworth lake overflowed into the Wardle lake through the above-mentioned gap, until its waters sank below 950 feet.

The Irwell lake must by this time have become much larger. That the ice-barrier north of the Rossendale highland was higher at this stage than that on the south is proved by the fact that two dry overflow-channels occur at the head of the Limy-Water valley, which cut below 1000 feet and down to 1050 feet respectively, and are both directed s o u t h w a r d s. With a higher ice-barrier on the south, they must have been directed northwards. They were produced at a later stage by an overflow from small

lakes formed when the ice-edge stood close to the watershed south of Burnley.

In the whole of the Upper Irwell basin there is no outlet lower than the gap south-east of Bacup, except the natural outlet at Rawtenstall. The water must, therefore, have escaped in that direction when the channel south-east of Bacup was abandoned. There are no overflow-channels in the Irwell Valley south of Rawtenstall, until we come to the ridge south-west of Knowl Hill, which is cut by a series of channels—the highest beginning at 950 feet.

Northwards, however, the watershed is cut below 800 feet by an overflow-channel near Baxenden, but the channel is directed southwards. It is evident, therefore, that the valley at Baxenden was blocked by ice from the north, and the main Irwell Valley was filled with ice up to a lower altitude (950 feet) on the south when the Irwell lake overflowed directly into the Roch Valley. The retreat of the ice south-west of Knowl Hill thus led to the abandonment of the direct overflow from the Irwell lake into the Whitworth lake.

The Irwell lake discharged its waters into the now augmented Naden lake, which again overflowed into the Whitworth lake by a long, wide, curving channel that trenches the watershed from 900 to below 825 feet. The first outlet from the Whitworth lake below 900 feet is south of Rushy Hill, where two parallel dry channels occur. The drainage through the higher of these entered the Wardle lake and escaped by a series of overflows into a lake at the head of the Roch Valley and so into the Walsden channel. It is likely that the earliest drainage through the lower channel south of Rushy Hill also escaped by the same route; but, by the time that the valley had cut to its lowest level, the ice-barrier had retreated sufficiently to permit of the mingling of the waters of the Wardle lake with those of the Rochdale lake. Later, as the water-level sank a little lower, the two lakes were partly separated by the lateral moraine that stretches across the Wardle valley on the south, and the Wardle lake began to be drained into the Rochdale lake.

In the fourth stage, the chief factor was the great overflow-channel now occupied by the Cheesden Brook and its connexions. This channel cuts through the ridge between the Irwell and Roch basins at Birtle Dean as a steep-sided gorge over 200 feet deep. The Irwell lake commenced to drain into it at an altitude of 900 feet, and its lowest feeder entered below 750 feet. The water draining through Birtle Dean was distributed by channels at various levels, the earlier portion ultimately passing through the Walsden gorge. The later portion, however, cut a wide channel 30 feet deep, which terminates in a large delta between 500 and 525 feet O.D., and therefore could not have drained through the Walsden gorge. This stage was also marked by the draining first of the Whitworth lake, and then of the lake in Naden Dean, and by a great increase in the area of the Rochdale lake.

The overflow-channels on the eastern slopes of the Roch Valley are more sporadically distributed, and less easy to arrange in series than those described above. The first stage is marked by a single channel east of the Walsden gorge, which must have been formed when the present gorge was filled with ice up to and somewhat north of the Pennine watershed. A small lake occurred at the head of this channel, but there was doubtless a considerable flow of water towards it between the edge of the ice and the steep slopes of Blackstone Edge.

The second stage is marked by the overflow from a lake at the head of Longden-End Clough across the ridge to the north. Two sets of small channels (commencing at altitudes of 1225 and 1150 feet) conducted the drainage northwards through narrow lakes, the last channel in the series being 125 feet deep on its watershed, which is at an altitude of about 760 feet. This channel terminates close to the entrance to the Walsden gorge.

The third stage began with a great lake occupying the Tame Valley at an altitude of 1125 feet, which drained northwards into a lake at the head of the Ogden valley (altitude 1100 feet) and thence into the Longden-End lake, from which the water escaped below 850 feet. The last channel in this series is 75 feet deep on its watershed, which was cut down to 675 feet.

The fourth stage is marked by a series of valleys parallel with those of the third stage, but terminating some 50 feet below, the great channel from the Tame lake being in operation during the earlier part of this stage. The last-mentioned channel cuts down below 625 feet.

During the fifth stage, a slight overflow of the water impounded against the eastern slopes of the Beal valley entered the lake in the Ogden valley, then at an altitude of 700 feet. The Ogden lake drained northwards into a smaller lake, and then into the Rochdale lake, the last overflow-channel cutting below 600 feet. This stage began with the merging of the Longden-End lake into the Rochdale lake.

A slight retreat of the ice-barrier led to direct overflow from the Ogden into the Rochdale lake, the channel between the two being cut down below 600 feet before it was finally abandoned and the Ogden lake became part of the Rochdale lake. A lake now existed in the Beal valley, which drained northwards into the Rochdale lake. This valley continues southwards, but the lowest altitude of its watershed is well over 600 feet, whence we may infer that the waters of the Rochdale lake could not escape in that direction. More probably a northward flow of water took place through this gap into the Beal lake.

It has been stated that two of the terminal overflow-channels cut down below 600 feet. These are typical dry gorges, and are both directed northwards towards the Walsden gap. The floor of the Walsden gorge is 610 feet on the watershed, and is so level that

a stretch of canal three-quarters of a mile long crosses the watershed without a lock. The sides of the gorge rise precipitously to a height of over 300 feet above its floor, Several streams have cut out notches in its walls and deposited the débris upon its floor. The actual watershed is a delta-watershed or 'corrom,'[1] the sediment being deposited by Light Hazzles Brook, which descends from the east and is deflected southwards by the 'corrom.' A cutting was made in the 'corrom' below 600 feet in the construction of the canal, and an exposure of alluvium may now be seen in the bank passing below the surface of the water. It is clear that the rock-bottom of the gorge extends considerably below 600 feet, and would thus provide an outlet for the drainage conveyed by the two channels mentioned above, as the 'corrom' could not be formed until after the Walsden overflow-channel was abandoned.

A great amount of morainic material occurs in the Roch Valley south and south-west of Rochdale. This is traversed by a number of dry channels directed southwards, in addition to the gorge which the Roch now occupies. The highest of these channels occurs about 2 miles south of Rochdale, and is cut down below 550 feet. The opening of this outlet must have been the cause of the abandonment of the Walsden channel.

(*c*) The Western Series.

It has been shown that, near the time when Birtle Dean ceased to operate as an outlet of the Irwell lake, the Walsden gorge was abandoned. Hence the drainage from all the overflow-channels now to be described was confined to the western side of the Pennines. The channels south-west of Birtle Dean mark the last stages of the separation between the Irwell lake and the Rochdale lake.

During its later history, the Irwell lake was augmented by the overflow from a lake south-east of Accrington which cut a channel below 800 feet between Baxenden and Haslingden. The retreat of the ice northwards across this watershed removed the last source of supply of ice to the Irwell Valley north of Ramsbottom. West of the Irwell Valley, the Rossendale highland is less uniformly high, and, being traversed by valleys from north-west to south-east, besides projecting farther west, was crossed by considerable streams of ice. The long persistence of the ice-barrier against the ridge north-east of Bury may have been largely due to the convergence of these ice-streams upon the basin-like hollow in which Bury is situated, in addition to the tendency of the ice that poured over the

[1] P. F. Kendall & E. B. Bailey, 'The Glaciation of East Lothian south of the Garleton Hills' Trans. Roy. Soc. Edin. vol. xlvi, pt. 1 (1907–08) pp. 25–30.

plain along the south of the Rossendale highland to press northwards up the Irwell Valley.

The overflow-channels on the eastern slopes of the Darwen-Edgeworth valley indicate that it was occupied by an ice-stream from the north at a comparatively late stage, for the drainage from one of these channels probably entered the Irwell lake while it was still separated from the Rochdale lake. The big channel at Hawkshaw Lane was, however, cut by the overflow from the Edgeworth lake into the Irwell lake, after the ice-barrier had shrunk away from the ridge north-east of Bury. The Edgeworth lake was fed by the overflow from lakes in the Darwen and Hoddlesden valleys north of the watershed, and from a lake in the Belmont valley. In all probability the Edgeworth and Belmont lakes were united before the Hawkshaw-Lane channel was abandoned. The Belmont lake then discharged its waters eastwards into the Irwell lake through a gap below 500 feet due west of Bury, and later directly into the Irwell lake; the latter overflowed south-eastwards, reinforced by the drainage from the Burnley lake by way of the overflow-channels west of the Rossendale highland. It is, therefore, certain that the Cliviger overflow-channel continued in operation at a much later stage than the Walsden channel. The channels west of the Rossendale highland extend in a broad arc, convex towards the west, from a few miles south of Blackburn to Horwich, where they open upon an alluvial plain built of the débris derived from their excavation. The altitude of the ice-barrier corresponding with the highest series fell gradually, from about 750 feet on the north to below 600 feet on the south. The Brinscall channel is cut down below 550 feet, and at the same altitude another series was initiated over a mile away to the north-west: the main channel being about 100 feet deep, and cutting its watershed down to 350 feet above O.D. This series, although much obscured by recent stream-action, may be traced through Chorley to Wigan and Leigh, and marks the last stage during which the Ribble drainage escaped into the Mersey basin.

The absence of any large and deep valleys of the ordinary type at the western extremity of the Rossendale highland, and the fact that the valleys that do exist open more or less towards the direction from which the ice came, prevented the formation of any but insignificant lakes to break the continuity of the overflow-channels. Though some of the channels are wide and deep rock-gorges, many were wholly or partly excavated in Drift; and their western walls frequently consisted entirely of ice, or were supplemented above by the ice-barrier.

Prof. Boyd Dawkins [1] has shown that the contour of the present surface, here and over the plain to the west and south, is much less

[1] 'The Relation of Geology to Engineering' Proc. Inst. C.E. vol. cxxxiv (1897–98) pp. 269–70.

diversified than that of the pre-Glacial surface, buried valleys being met with in boring and in excavations, some of which extend considerably below sea-level.

Immense quantities of the rock-débris resulting from the excavation of overflow-channels, mixed with rearranged Drift, were deposited along the southern margin of the Rossendale highland, and the effects produced by strong currents in the shallow lakes which latterly occupied the South Lancashire plain make it easy to understand how these superficial deposits were long regarded as of marine origin.

Although its consideration opens up another chapter in the Glacial history of the Western Pennines, it may be stated here that, on the abandonment of the Walsden channel, the drainage of the Irwell-Mersey basin for some time escaped into the Trent basin and possibly into that of the Severn, until the ice-barrier between North Wales and the Rossendale highland was removed.

VI. Conclusions.

Three types of Drift have been recognized in East Lancashire, namely :—(1) North-Western Drift, which contains, among other materials, igneous rocks from the Lake District and the South of Scotland; (2) Ribblesdale Drift, containing Carboniferous Limestone and chert and Silurian grit; and (3) Local Drift, consisting of materials that can be found *in situ* in the neighbourhood.

The distribution of these types of Drift, together with the evidence of striated and of disturbed rock-surfaces beneath the Drift, suggests that East and South Lancashire were invaded by the composite ice-sheet from North Lancashire and North-West Yorkshire postulated by Mr. Tiddeman. This ice-sheet reached up to the Pennine watershed, and lobes of ice crossed the watershed by way of the gaps at Widdop, Gorple, Cliviger (between Burnley and Todmorden), and Walsden (between Rochdale and Todmorden).

While the main ice-movement was from north-north-west to south-south-east, on the north and north-east of Manchester there was a curious movement of the ice partaking of the nature of an eddy, whereby the ice-flow was directed first eastwards, then north-eastwards, and ultimately northwards, the main current of ice thus bending completely back upon itself in the neighbourhood of Rochdale.

The Local Drift is believed to have been produced by the overlapping of 200 feet or so of clear ice, forming the upper portion of the ice-sheet, beyond the limits reached by the ice containing erratics. No evidence has been found in favour of any local glaciation in this area. A conservative estimate of the gradient of the surface of the ice, based upon the mapping of the limit of the North-Western Drift, gives a rise of about 4 feet per mile from the Pennines

(near Blackstone Edge) westwards towards the Irish Sea; this would involve the existence of an ice-sheet, rising to an altitude of approximately 2100 feet above present sea-level, in the middle of the Irish Sea, in the latitude of Bolton.

Extensive systems of glacier-lakes and drainage-channels were produced on the retreat of the ice. One system converged upon the Cliviger valley, by which the surplus waters on the west of the Pennines, south of Boulsworth Hill, crossed the Pennine watershed and escaped into the basin of the Yorkshire Calder. This continued until the ice had retreated so far as to expose a lower portion of the Rossendale highland east of Chorley. The drainage from the basin of the Ribble then escaped southwards, cutting a system of large overflow-channels in this neighbourhood.

For a long time the Irwell basin discharged its surplus waters by way of the Walsden gorge into the Yorkshire Calder, thereby giving rise to a very complicated system of overflow-channels.

The Cliviger overflow-channel remained in use at a later stage than the Walsden channel, and the evidence of the Drift-distribution and the overflow-channels is in favour of a greater altitude of the ice-barrier on the northern than on the southern side of the Rossendale highland, at the maximum extension of the ice-sheet and during all the stages of its retreat. As the ice-sheet dwindled, its two components apparently separated in the neighbourhood of Burnley and the North-Western ice-barrier retreated westwards, while the glacier between Pendle and Boulsworth Hills retreated northwards. It appears likely that the North-Western ice arrived in this area later, and disappeared earlier, than the Ribblesdale ice. This was doubtless owing to the fact that the former was much farther from its source than the latter.

The arrangement of the overflow-channels and of the Drift-deposits indicates some slight local fluctuations in the ice-sheet, but there is no evidence in this area for more than one glacial period.

In conclusion, I wish to thank Mr. S. Compston, J.P., through whose kind offices I was permitted to examine and make excavations in the gathering-ground of the Bury and District Joint Water-Board; also Mr. J. McV. Munro, who accompanied me on many long walks over the moors; and, above all, Prof. P. F. Kendall, to whose generous help and encouragement the completion of this work is largely due.

VII. Appendix.

Instances[1] of 'Terminal Curvature' of Rocks underlying Drift.

(In all these the pressure has acted up hill.)

Locality and Elevation.	Description of Section.	Direction of Pressure.
1. Black Clough Head, south of Boulsworth Hill; 1370 feet.	2 feet of Boulder Clay resting on 4 feet of crumpled shale—undisturbed shale below.	East.
2. Birkin Clough, south of Widdop Cross; 1350 feet.	Big boulders forced into shale.	South.
3. Mere Clough, 2 miles south-east of Burnley; 740 feet.	1 foot of sandy Boulder Clay; boulders forced into a broken-up surface of flaggy sandstone.	South-East.
Green's Clough, south-west of Portsmouth (Cliviger gorge);		
4. 1250 feet.	Thin Drift on shale; shale contorted at the surface.	South.
5. 1300 feet.	Clayey gravel on 18 inches of shale, contorted and dragged over. Undisturbed shale below.	South-East.
6. North of the summit of Heald Moor; 1300 feet.	Boulder Clay worked into contorted shale.	South-East.
7. Anchor Clough, north-east of Ramsbottom; 1295 to 1350 feet.	Clay with subangular boulders, resting upon and mixed with 18 inches of contorted and broken-up shale. Undisturbed shale below.	South-East.
8. Above 'Long Causeway,' east of the Wardle valley; 1100 feet.	Boulder Clay worked into contorted shale. Undisturbed shale below.	North.

[1] Indicated on the map (Pl. XXXIII) by dotted arrows.

EXPLANATION OF PLATES XXXI–XXXV.

Plate XXXI.

Fig. 1. General view of overflow-channels south-west of Knowl Hill; the view is taken looking north-north-westwards. The course of the main channel, indicated by the factory chimneys, runs along the hillside from north-west to south-east, instead of following the direction of steepest slope, north-east to south-west. The channel has a broad flat floor, and is occupied by a comparatively small stream. Thick Drift occurs on the left of this valley. (See p. 221.)

2. View looking northwards from nearly the same position as in fig. 1. The flat-topped hill on the sky-line is Knowl Hill (1378 feet). The ridge running southwards from Knowl Hill is cut across by two channels (⟶) directed eastwards. The higher of these, Wind-Hill Nick, is a dry gorge (Pl. XXXII, fig. 1); the lower, Birtle Dean, is a continuation of the main channel mentioned above (fig. 1), and is over 200 feet deep. Wind-Hill Nick cuts the ridge at 900 feet, and Birtle Dean at 850 feet above O.D. (See p. 221.)

Plate XXXII.

Fig. 1. View of the entrance to the Wind-Hill dry channel, looking south-eastwards. (See also Pl. XXXI, fig. 2.) This is a beautifully-formed valley, 50 feet deep on the watershed, cut in Millstone Grit. Its floor slopes eastwards, away from the observer.

The hillside on the left of the picture is scarped, and formed one side of the drainage-channel—the other side consisting, at this point, largely of ice—which carried the water to Wind-Hill Nick. This channel was cut down a little farther, after Wind-Hill Nick was abandoned. It will be noted how the stone wall which crosses the floor of the channel is partly hidden by the low right bank. (See p. 221.)

2. View, looking south-south-westwards, of the lower portion of Ratcliffe Hill dry channel, south of Shore Moor. This channel is over 100 feet deep on the watershed, and is directed northwards, all the normal drainage here being directed southwards. The floor of the channel widens, and terminates in a gently-sloping delta at about 825 feet O.D., below which the hillside is steeper. The hill on the left is 950 feet above O.D. (See p. 220.)

Plate XXXIII.

Map, on the scale of 3 miles to the inch, or 1 : 190,080, illustrating the distribution of the three types of Drift in East Lancashire.

Plate XXXIV.

Map, on the scale of 3 miles to the inch, or 1 : 190,080, indicating the chief overflow-channels (shown in red) and the various positions of the edge of the ice at its maximum extension, and at well-marked stages during its retreat. [*For* 'Black Hameedon' *read* 'Black Hameldon.']

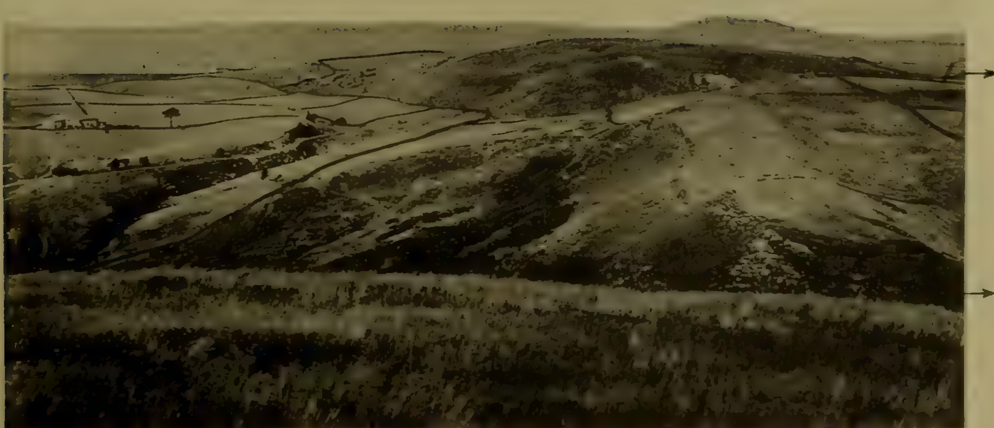
Plate XXXV.

Reduction, on the scale of about 5 miles to the inch, or 1 : 316,800, of the above-mentioned map (Pl. XXXIV), showing the glacier-lakes and overflow-channels in existence at the more important episodes during the retreat of the ice-sheet.

Fig. 1. General View of Overflow Channels south-west of Knowl Hill.

A. J., Photo.

Fig. 2. View, looking northwards, from nearly the same position as in Fig. 1.



A. J., Photo.

Bemrose, Collo Derby

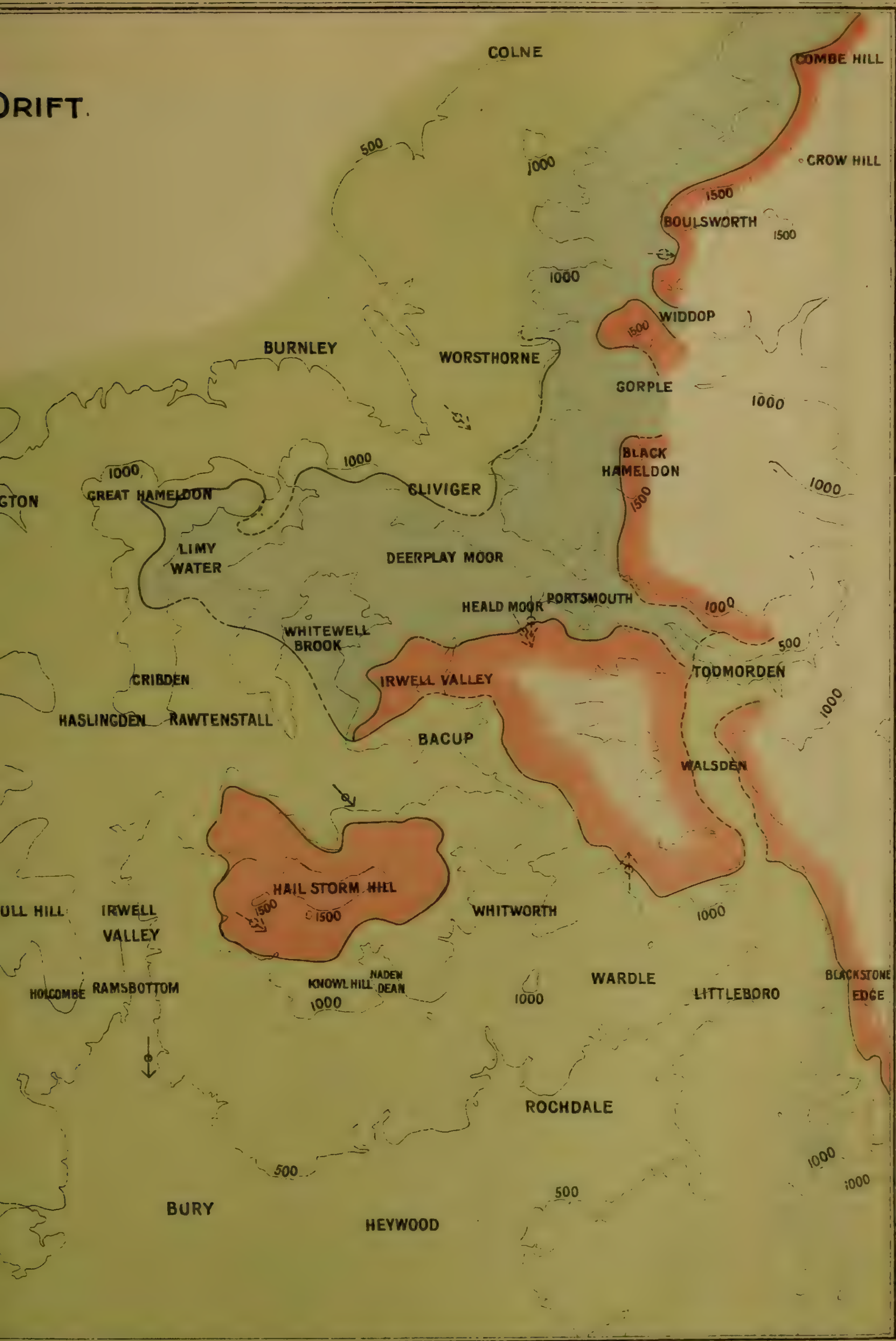
Fig. 1. View of the entrance to the Wind Hill Dry Channel, looking south-eastwards.

A.J., Photo.

Fig. 2. View, looking south-south-westwards, of the lower portion of the Ratcliffe Hill Dry Channel.

A.J., Photo.

Bemrose, Collo., Derby



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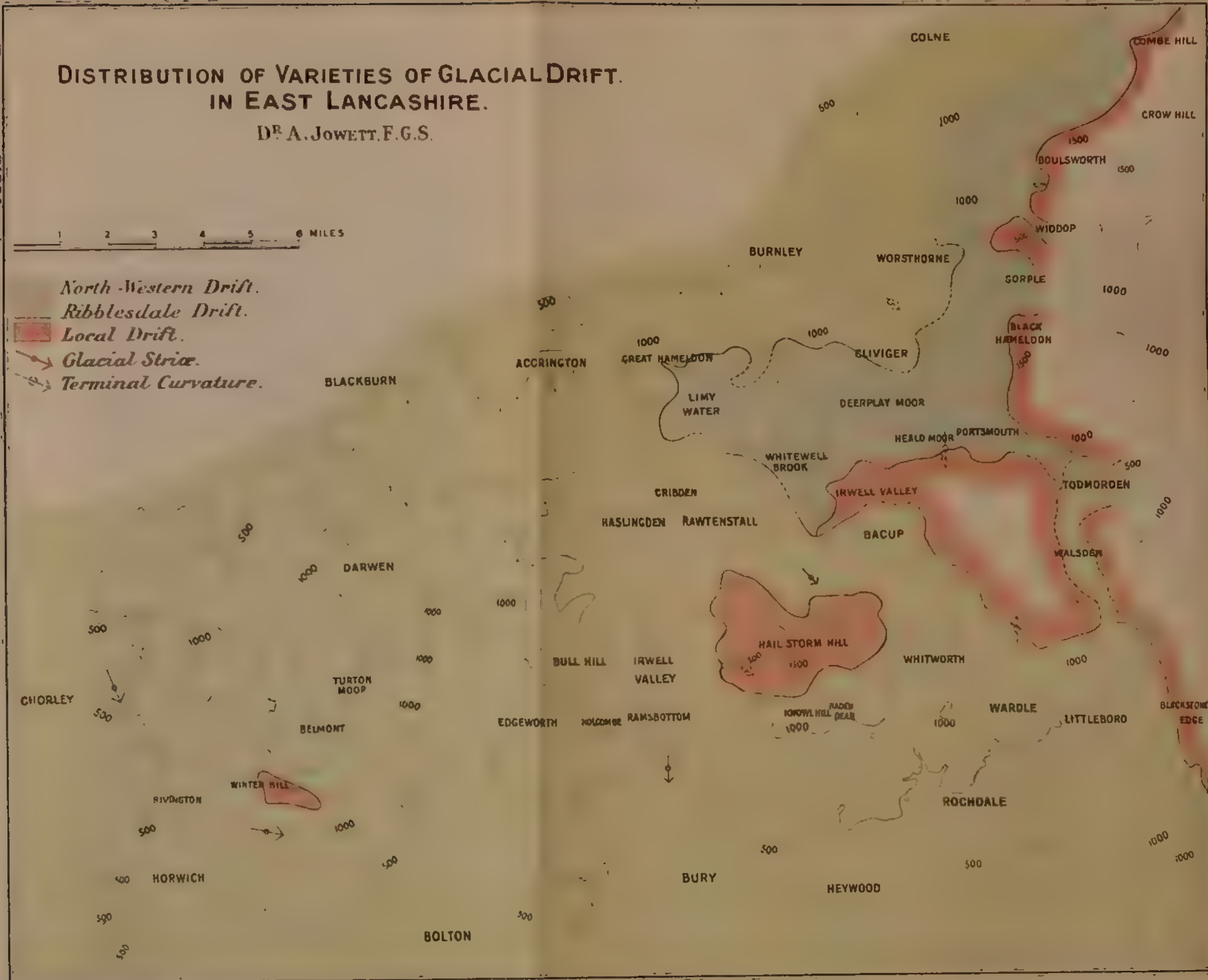

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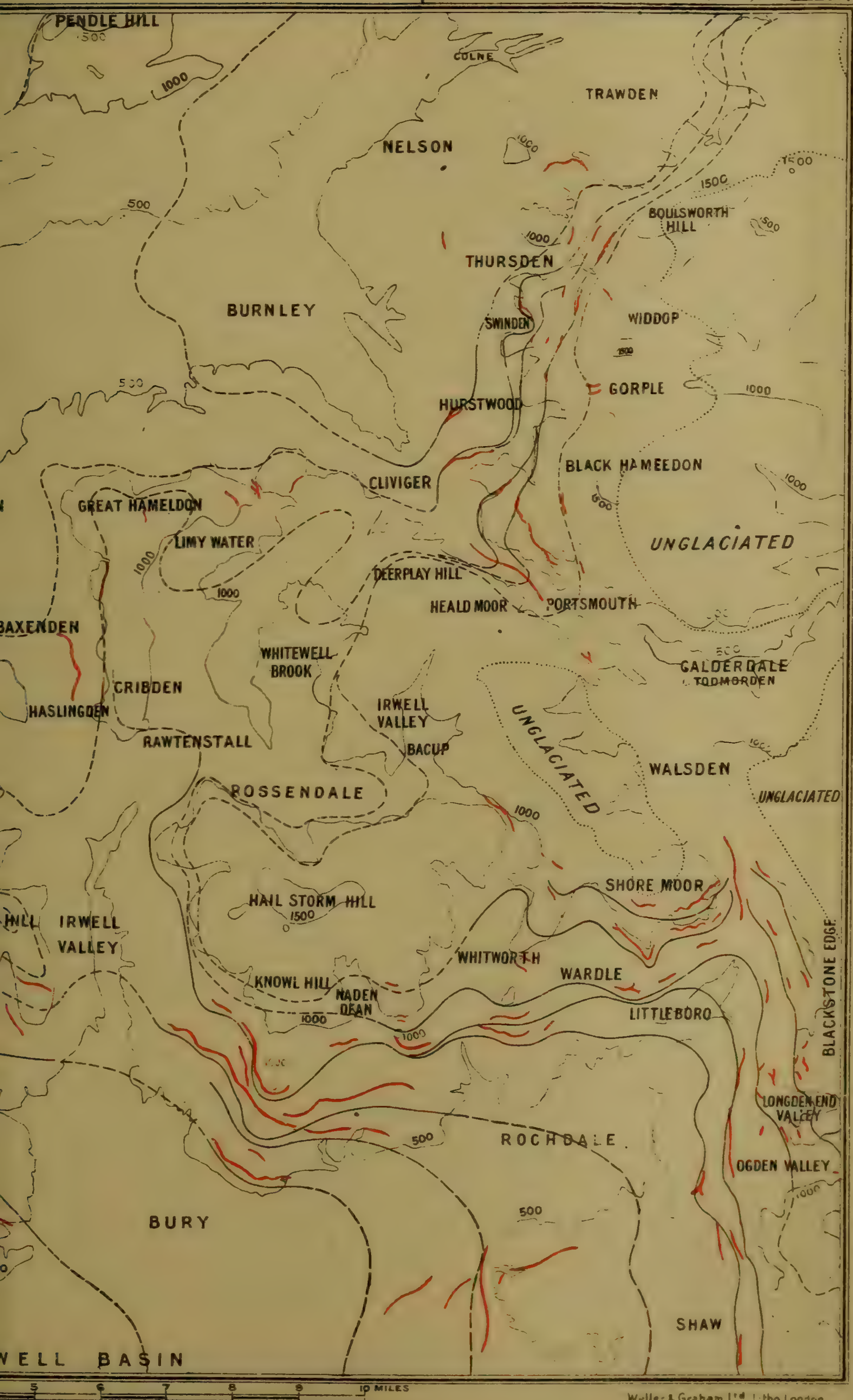

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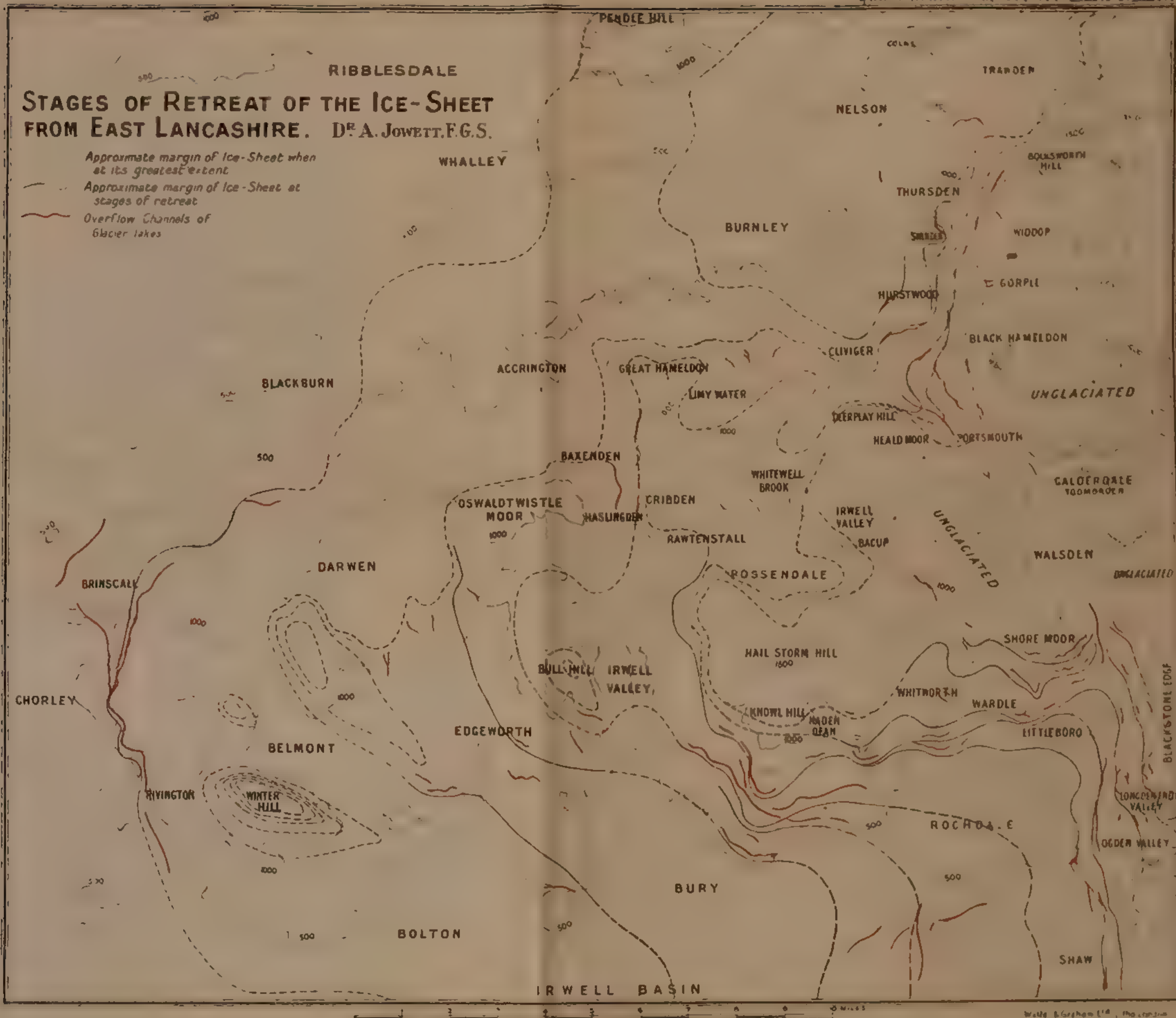
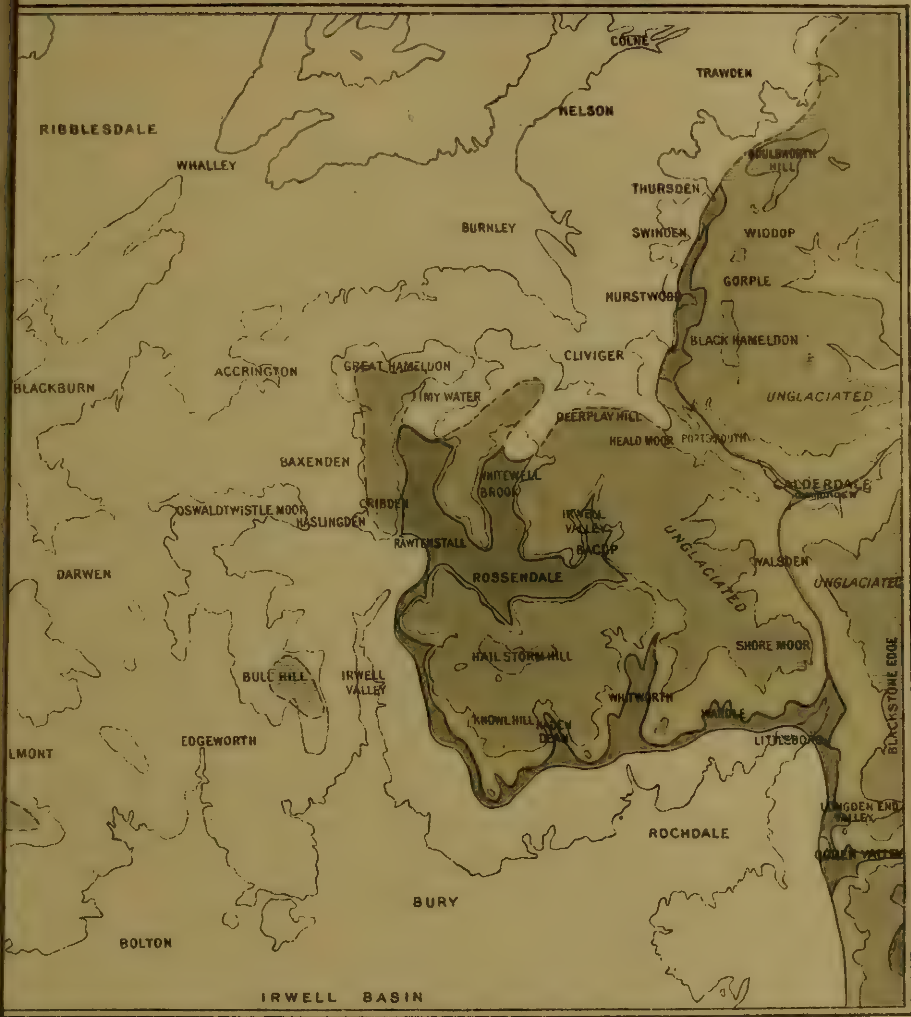

STAGES OF RETREAT OF THE ICE-SHEET FROM EAST LANCASHIRE. Dr. A. Jowett, F.G.S.
Approximate margin of Ice-Sheet when at its greatest extent
Approximate margin of Ice-Sheet at stages of retreat
Overflow Channels of Glacier lakes
PENDLE HILL
RIBBLESDALE
TRAWDEN
NELSON
WHALLEY
BOULSWORTH HILL
THURSDEN
BURNLEY
WIDDOP
HURSTWOOD
GORPLE
BLACK HAMELDON
CLIVIGER
ACCRINGTON
GREAT HAMELDON
BLACKBURN
LIMY WATER
UNGLACIATED
DEERPLAY HILL
HEALD MOOR
PORTSMOUTH
BAXENDEN
WHITEWELL BROOK
CALDERDALE
TODMORDEN
OSWALDTWISTLE MOOR
CRIBDEN
HASLINGDEN
IRWELL VALLEY
RAWTENSTALL
BACUP
WALSDEN
DARWEN
BRINSCALL
ROSSENDALE
SHORE MOOR
HAIL STORM HILL
BULL HILL
IRWELL VALLEY
WHITWORTH
WARDLE
CHORLEY
KNOWL HILL
NADEN DEAN
LITTLEBORO
EDGEWORTH
BELMONT
BLACKSTONE EDGE
RIVINGTON
WINTER HILL
LONGDEN END VALLEY
ROCHDALE
OGDEN VALLEY
BURY
BOLTON
SHAW
IRWELL BASIN
500
1000
1500

S IN EXISTENCE AT EACH STAGE.

LARGE LAKES IN THE UPPER VALLEYS OF THE IRWELL AND ROCH,
AND OF A SMALLER SERIES IN THE RIBBLE BASIN.



Stages in the Retreat of the Ice-Sheet from East Lancashire: the Glacier-Lakes and their Overflow-Channels in existence at each stage.

Dr A. Jowett, F.G.S.

Explanation.

Unshaded area occupied by ice.

- *Glacier-lakes and overflow-channels.*
- *Over 1500 feet above ordnance datum.*
- *1000 to 1500 feet.*
- *500 to 1000 feet.*
- *Below 500 feet.*

Fig. 1. Approximate area occupied by the ice-sheet when at its greatest development.

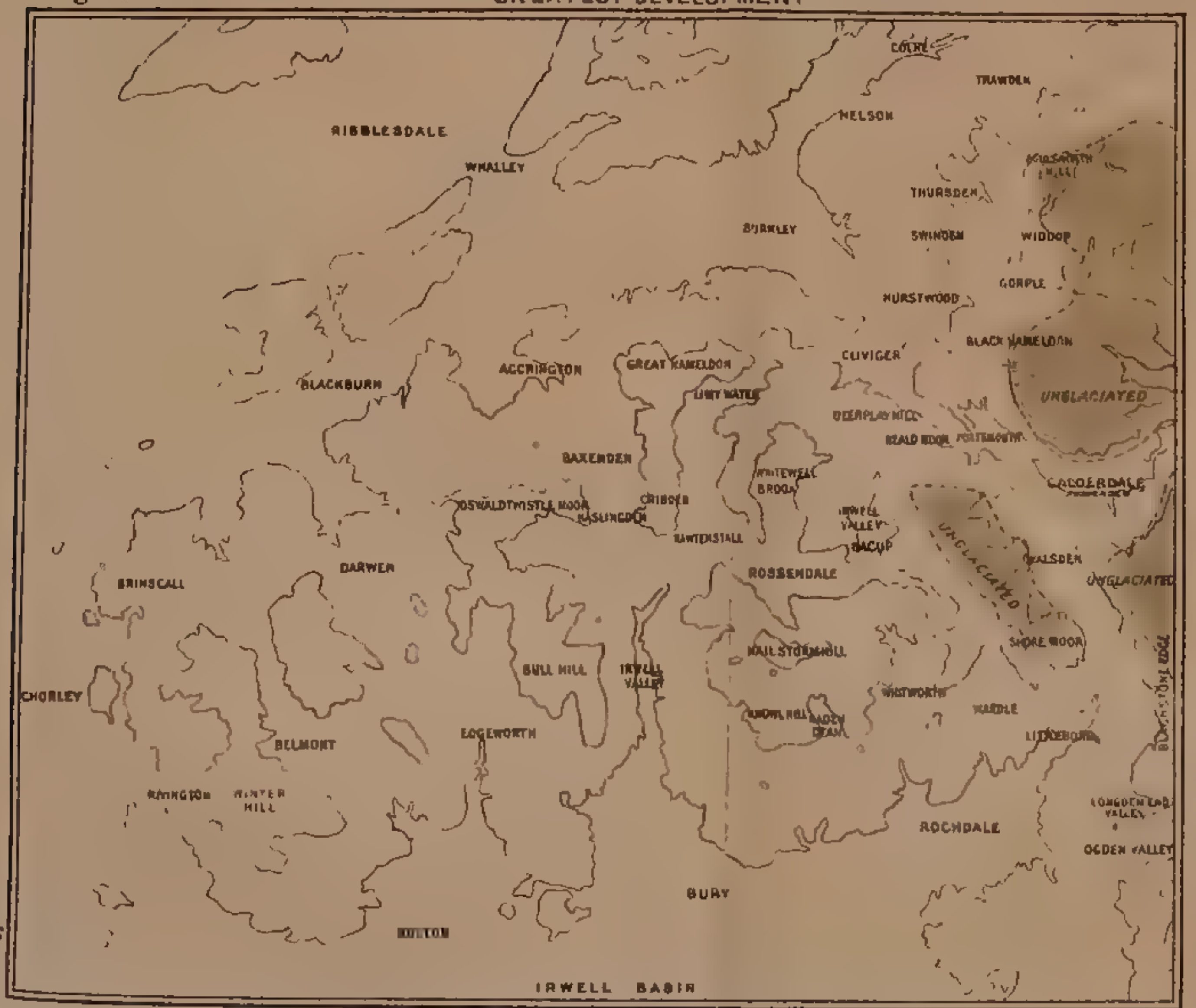


Fig. 2. Almost complete retreat of the ice west of the Pennine watershed.

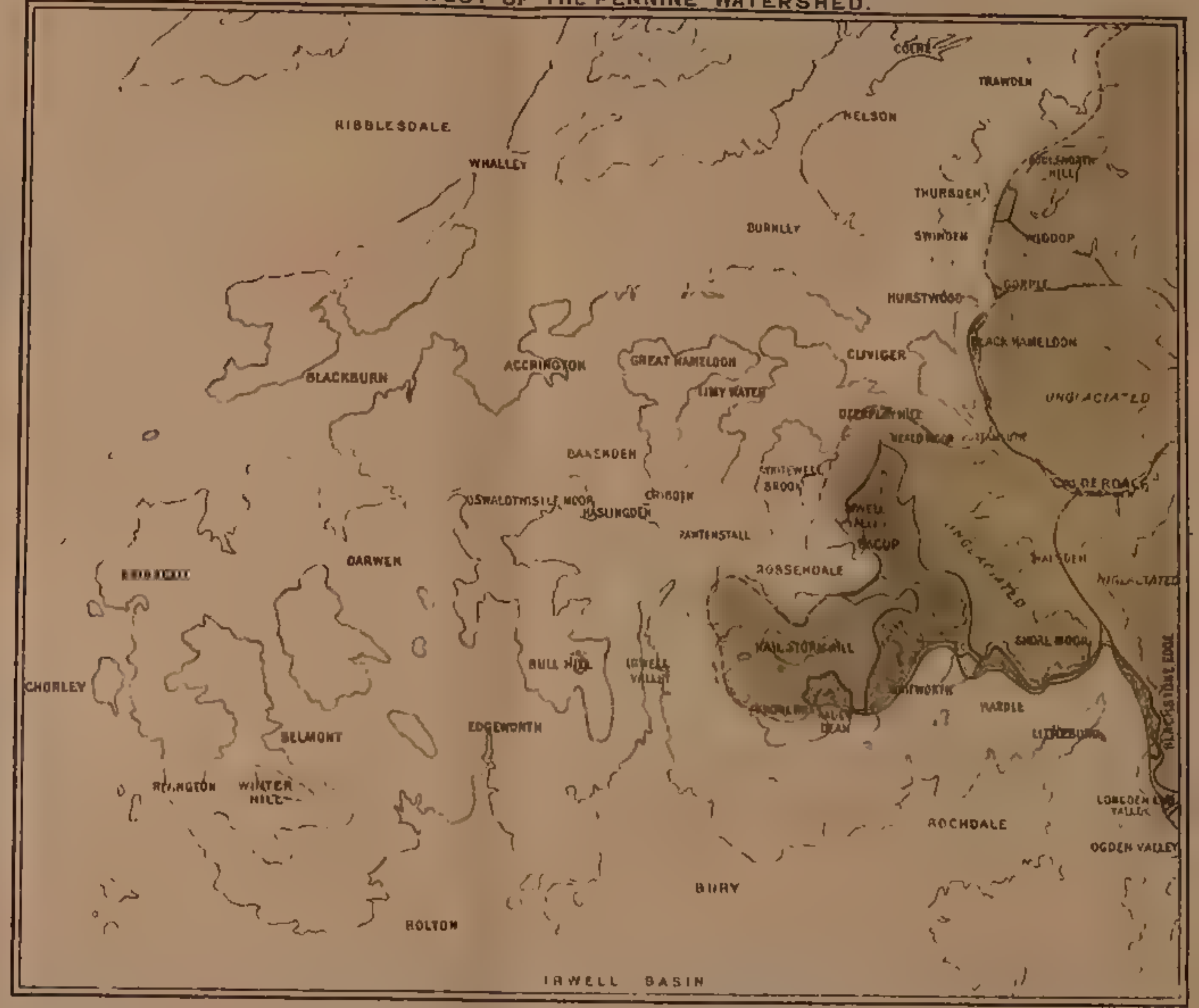


Fig. 3. Formation of large lakes in the upper valleys of the Irwell and Roch, and of a smaller series in the Ribble basin.

Fig. 4. Critical stage: lakes in the Irwell basin about to cease from discharging into Calderdale.

Fig. 5. Escape of the drainage from the Irwell-Mersey basin into that of the Trent.

SCALE 0 1 2 3 4 5 6 7 8 9 10 MILES

Fig. 6. Great increase in the size of the lakes of the Ribble basin. Severance of the eastern lobe from the main ice-sheet.

Fig. 1. This indicates approximately the area covered by the ice-sheet when at its greatest development. The ice-sheet extended beyond the Pennine watershed, a large lobe crossing north of Boulsworth Hill into Airedale; and two smaller lobes, one crossing south of Black Hameldon and the other east of Shore Moor, formed a combined stream in Upper Calderdale.

2. At this stage, the ice had almost completely retreated west of the Pennine watershed, except the lobe which (although steadily diminishing) continued to enter Airedale throughout all the stages here depicted. Lakes were held up by the ice-barrier, and their surplus waters were discharged across the Pennines into Calderdale. The summit of Winter Hill appeared above the ice-sheet.

Figs. 3 & 4. A further retreat of the ice-barrier led to the production of large lakes in the upper valleys of the Irwell and Roch, and of a smaller series in the Ribble basin, west of Boulsworth Hill and Black Hameldon. Fig. 4 represents the critical stage, when the lakes in the Irwell basin were about to cease from discharging into Calderdale.

Fig. 5. The drainage of the Irwell-Mersey basin next escaped into the Trent basin. The main outlet for the Ribble drainage was still by way of the Yorkshire Calder.

6. The lakes in the Ribble basin next increased considerably in size, and the whole of their surplus waters was discharged west of the Rossendale highland into the Irwell-Mersey basin, and thence into the Midlands. At this stage, the connexion between the main ice-sheet and the southward-flowing lobe between Pendle and Boulsworth Hills was severed.

Discussion.

Mr. R. H. Tiddeman wished to remind the Society that this paper was a sequel, and in his opinion a very valuable sequel, to a series of papers in the Society's Journal on the Glaciation of the North-West of England, which related to almost contiguous areas. These were:—in 1872, by the speaker, 'On the Evidence for the Ice-Sheet in North Lancashire & Parts of Westmoreland & Yorkshire'; in 1874 & 1875, by Clifton Ward, 'On the Glaciation of the Northern & Southern Parts (respectively) of the Lake District'; and in 1875, by J. G. Goodchild, 'The Glacial Phenomena of the Eden Valley & the Western Part of the Yorkshire Dale District.'

In the first paper the speaker had been irresistibly compelled by the evidence in his ground to hold the view that the Scottish and Lake-Country ice had held up the ice-drainage from North Lancashire, and compelled its flow to the south over land. His further conviction, deduced from facts by other observers, that the Irish Sea had been occupied by an ice-sheet which overflowed the Isle of Man, Anglesey, and the plains of Cheshire, was, he thought, now fully admitted.

The present paper so well worked out, illustrated, and presented, was strongly confirmatory of those views. The existence of overflow-channels discovered by the Author was very valuable, and the speaker was now well aware of many similar occurrences in his ground to the north, although they were not at the time recognized as such.

In conclusion, he wished to ask whether a flow of the Lake-Country ice across the débris of the Ribblesdale ice-stream might not more simply explain the mixture of drifts west of Walsden.

Prof. T. W. Edgeworth David stated that this interesting paper suggested to him an analogue between the glacial conditions just outlined for East Lancashire, and those of the Ross Region of Antarctica. The Ross Barrier might be compared with the Irish-Sea ice, and any of the great glaciers which join with it and nourish it with the Ribblesdale ice. Even now, the Ross-Barrier ice-sheet climbs slopes, and thrusts up marine muds for a vertical distance of 300 feet (formerly 800 feet), and it has accomplished this work at distances of at least 300 to 400 miles from the snouts of the great glaciers which push against its extreme southern margin. He wished to ask the Author whether in East Lancashire he had observed upthrust marine muds derived from the floor of the Irish Sea. The thickness assumed for the Irish-Sea ice (2000 feet), agreed well with the former thickness of the Ross-Barrier ice-sheet.

He congratulated the Author on a paper which advanced our knowledge of the Glacial deposits of Lancashire, a branch of geological knowledge to which Mr. Tiddeman had already made such important contributions for Lancashire, Prof. Kendall for Yorkshire and adjacent areas, and Mr. Lamplugh for the Isle-of-Man development of the ice-sheet of the Irish Sea. The paper seemed of especial value in regard to the detailed tracing of the lakes which formed between the Pennines and the retreating edge of the Irish Sea ice-sheet, and also with reference to the careful survey of the overflow valleys discharging eastwards across the water-parting of the Pennines,

He stated that the Author's suggestion that the undisturbed character of certain sandy beds under Lancashire Drift might be due to the sand being compactly frozen at the time, recalled an interesting paper by the President on the pre-Mesozoic glacial beds in the Varanger Fjord. Dr. Strahan had recorded in that paper that Mr. L. L. Belinfante had offered a similar explanation for a similar occurrence in the Varanger Fjord.

Mr. G. W. Lamplugh congratulated the Author on his choice of an area which combined so admirably with the previous work. He commented on the similarity of glacial conditions on both sides of the Irish-Sea Basin and on the eastern side of the North Sea. In all three cases the local ice-flow was pent in and deflected along the bordering uplands. The Southern Pennines appear to have had curiously little influence as a contributory area, but to have been glaciated only where invaded. During the period of recession there must have been an enormous quantity of water pouring over the middle of England, as the overflow-channels and other phenomena indicate persistently an inland flow from both sides of the country. It was not yet clear where all this water ultimately went.

Dr. J. W. Evans remarked that, when the Author inferred from

the position of the overflow-channels the extent of the lakes and the direction of the drainage at different stages of the retreat of the ice, he assumed that the relative heights of the surfaces of the country were the same as at present. The speaker, however, believed that the accumulation of many hundreds of feet of ice on the lower ground would result in a depression of that portion of the region relatively to the area left uncovered, while the subsequent disappearance of the ice would cause a gradual reverse movement. Such movements should be allowed for in dealing with the problems presented by the facts recorded in the paper.

The Author, in reply to Mr. Tiddeman, instanced the well-defined boundary between the North-Western and the Ribblesdale Drifts and the almost complete absence of boulders of igneous rocks from the latter, as evidence that the ice-streams which deposited these two types of Drift did not commingle to any appreciable extent.

The Author informed Prof. David that marine deposits are widely distributed among the Drift: thus, marine shells had been obtained by Mr. Bolton from the Boulder Clay at Bacup.

Replying to Dr. Evans, the Author stated that he had carefully considered the influence of a possible warping of the land-surface upon the overflow-channels, but that a simpler interpretation was sufficient to explain the few difficulties that occur.

In conclusion, he thanked the Fellows for their kind appreciation of his work.

9. *On the* Lithology *and* Composition *of* Durham Magnesian Limestones. By Charles Taylor Trechmann, B.Sc., F.G.S. (Read February 4th, 1914.)

[Plates XXXVI & XXXVII—Microscope-Slides.]

Contents.

I. Introduction.

The analyses of which a selection is here presented were commenced during an investigation of the Magnesian Limestones of the southern part of the Durham area. The results proved of sufficient interest to induce me to extend the enquiry over a considerable variety of rocks included in the whole Permian area of Durham.

The work was undertaken, primarily in order to obtain satisfactory and reliable information regarding the following questions:—

(1) The quantity and nature of the insoluble residues in the rock;
(2) The amount of iron, together with the traces of alumina and phosphoric acid accompanying it, and the state of oxidation of the former;
(3) The dolomitic or non-dolomitic character of the various beds; and
(4) The possibility of sulphates still remaining in the rock.

I was also desirous of gaining information, if possible, regarding the original condition of deposition of the formation, by analysis of those parts which had undergone little, or relatively little, subsequent alteration; and I also wished to ascertain to what extent those portions which have a calcareous composition might be regarded as the result of original conditions of deposition, of escape from secondary dolomitization, or of subsequent calcareous segregation.

The advisability of further analytical investigation was recently emphasized by some significant remarks, which Prof. E. J. Garwood and Mr. E. E. L. Dixon made during the discussion of a paper by Dr. D. Woolacott.[1] Among the questions asked during this discussion were the following:—

(*a*) What precisely was the agency which deprived a dedolomitized limestone of its magnesium?

(*b*) What was the evidence that any of the dolomite was an original chemical precipitate?

The only extended series of analyses of English Magnesian Limestones is that of E. J. J. Browell & J. W. Kirkby.[2] The specimens were selected by Kirkby, and analysed in Browell's laboratory. A critical examination of this paper shows that the analyses are mainly concerned with Marl Slates, Lower Limestones, and the concretionary growths and their associated matrix in the Upper Limestones of Fulwell.

The authors find that their analyses indicate variations from a rock containing 96·94 per cent. of calcium carbonate and 1·66 of magnesium carbonate, to one containing 42·84 per cent. of the former and 49·86 of the latter. At least six out of their forty-five analyses give quantities of magnesium carbonate in excess of the dolomitic ratio. The chief conclusion arrived at by them is that

'the differences in chemical composition are largely due to the action of segregation after deposition,'

of which the most conspicuous example is cited—the botryoidal and cannon-ball concretions. They also conclude that

'the light-coloured, friable beds contain the most magnesia, while the dark compact beds are the most calcareous,'

a conclusion only applicable to the sulphate-free and oxidized rocks as they appear at the surface, and not to the formation in its more original condition—as proved in sub-Triassic borings or in other protected situations. They also remark upon the smallness of the insoluble residues.

There can be no doubt that the bewildering inconstancy in the dolomitic character of the analyses obtained by Browell & Kirkby is largely due to an indiscriminate choice of partly-segregated rocks.

[1] Q. J. G. S. vol. lxvii (1911) p. 314.

[2] 'On the Chemical Composition of Various Beds of the Magnesian Limestone & Associated Permian Rocks of Durham' Nat. Hist. Trans. North. & Durham, vol. i, pt. 2 (1866–67) p. 204.

In the analyses tabulated in this paper, care was taken, both to ascertain the degree of alteration which the rocks had undergone, and to obtain average samples of the material free from secondary calcite or other crystals.

The following criteria were used in the recognition of beds which have escaped segregation or granular collapse :—

(*a*) General well-stratified character of the rock, whether massive or fissile, compact or friable.
(*b*) Fineness and uniformity of grain, together with the absence of secondary calcite or of powdery dolomite.
(*c*) The presence of casts of fossils in uncrushed or undisturbed condition.
(*d*) The presence in undisturbed condition of hollow cavities, presumably left after the solution of sulphates.

In a previous paper,[1] I endeavoured to point out the effect of the conversion of anhydrite formerly present in the formation into gypsum and its subsequent removal by solution, on the brecciation and degradation of parts of the Magnesian Limestone; as also its influence on the processes of segregation and liberation of granular dolomite, and on certain features connected with the tectonics of the formation.

The present paper is a sequel and extension of that just mentioned, based on a much closer enquiry into the composition of various beds. This being the case, a certain repetition of points already touched upon in the previous communication may perhaps be excused.

Repeated analyses[2] show that the Magnesian Limestone is essentially a dolomitic rock, the chief constituents of which may be roughly indicated by the following synopsis, though with no reference to their varying proportions :—

Previous Composition.	Present Composition.
Dolomite.	Dolomite.
Calcite.	Calcite.
Anhydrite and gypsum.	
Ferrous carbonate.	Iron sesquioxide.
Manganese carbonate.	Manganese dioxide (dendritic).
Sandy residue and colloidal silica.	Siliceous residues.
Sulphides.	Pyrites (free or enclosed in quartz).
Micaceous and heavy minerals.	Micaceous and heavy minerals.
Organic matter.	Bituminous matter.

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[1] Q. J. G. S. vol. lxix (1913) pp. 195–98.

[2] The process of analysis employed was the direct gravimetric one, with a double precipitation of the calcium and magnesium as oxalate and phosphate in well-diluted solutions. Confirmatory analyses were made in several cases. The results are further reckoned to terms of calcite and dolomite. Several of the rocks were sliced, and stained with Lemberg's solution. The quantity of superfluous calcite in the more dolomitic rocks in most cases agreed with that indicated by the degree of coloration on staining.

Samples were powdered and dried at 120° C. before analysis. Some estimations of carbon dioxide were also made, but were found to agree so closely with the calculated amount that this was neglected later.

II. Lithology and Composition.

South Durham Salt-Deposits.

I. Newcastle Chemical Works borehole, No. 1, on the bank of the Tees opposite Middlesbrough. Depth about 1052 feet.

A hard, grey, fetid, compact, partly oolitic, apparently thinly-bedded rock, impregnated with gypsum.[1]

	I.
Insoluble residue	1·05
FeO, etc.	0·46
$CaCO_3$	53·41
$MgCO_3$	44·40
$CaSO_4$	1·14
Total	100·46

Calcite .... 0·54   Dolomite .... 97·27

Highest Limestones. (Hartlepool and Roker Series.)

II. Fulwell railway-cutting.—A very white, powdery, well-bedded rock, containing friable siliceous concretions. No fossils. The coarser siliceous material was removed by riddling.

III. Hesleden Dene.—A thinly-bedded, very porous, white, friable oolite, made up of small and irregular concentric grains. Full of hollow casts of four species of Upper Limestone fossils.

IV. Hesleden Dene.—A white, massive, friable, well-bedded rock, containing fossils similar to those found in No. III, but less plentifully. It is quarried as a building-stone.

V. Hartlepool shore-section.—Massive well-bedded oolite. No fossils occur, but the bed is closely associated with fossiliferous Upper Limestones.

VI. Seaham Harbour.—In a mass of rock isolated from the cliff-section. A bed about 2 feet thick near the middle of the section: it is a very small-grained oolite, each grain hollow in the centre. This bed is full of empty stellate cavities. No fossils; but *Schizodus* and *Liebea* occurred in a bed immediately below it.

A stained section shows this rock to have been originally a fine-grained oolite, the nuclei being dissolved out, and the concentric structure nearly obliterated by recrystallization of the dolomite in small, irregular, allotriomorphic crystals. The presence of calcite is shown by a faint general stain, but it does not occur in well-defined crystals. (See Pl. XXXVII, fig. 5.)

[1] The analysis is of the actual fragment in which Richard Howse detected the three characteristic Upper Zechstein fossils—*Schizodus dubius*, *Liebea hausmanni*, and *Chondrites virgatus*. See Nat. Hist. Trans. North. & Durham, vol. x, pt. 2 (1890).

	II.	III.	IV.	V.	VI.
Insoluble residue ...	3·31	0·76	0·45	0·05	0·58
Fe_2O_3, etc.	1·18	0·45	0·30	0·40	0·44
$CaCO_3$	52·96	54·85	55·41	54·79	54·49
$MgCO_3$	42·13	45·02	45·01	45·13	44·84
SO_3	0·15	0·08	tr.	tr.	tr.
Totals	99·73	101·16	101·17	100·37	100·35
Calcite	2·80	1·25	1·82	1·06	1·10
Dolomite...............	92·29	98·62	98·60	98·86	98·23

Upper Limestones with *Chondrites*.

VII. Coast-section north of Blackhall Rocks.—A fine-grained, whitish-yellow, soft, fetid, soapy rock, well-bedded but much fractured. Full of hollow casts of *Schizodus*, *Liebea*, and *Chondrites*.

VIII. Coast-section south of Blackhall Rocks, associated with beds similar to the above. A fine-grained, white, soft, fetid, soapy rock, well-bedded and full of stellate cavities.

A stained section shows a compact aggregate of very minute dolomite-grains, yellow with impurities. Calcite occurs throughout the slide as minute specks which stain deeply. Irregular quartz-grains and tourmaline-needles are visible.

	VII.	VIII.
Insoluble residue .... (rather oily).	2·61	3·80
Fe_2O_3, etc.	0·93	0·77
$CaCO_3$	52·76	53·14
$MgCO_3$	42·67	42·28
SO_3	0·31	0·17
Totals	99·28	100·16
Calcite	1·96	2·81
Dolomite	93·47	92·61

Concretionary Beds.

Coast-section between Blackhall Rocks and Hart.—The powdery matrix is here largely removed, leaving the concretions in fallen masses. Associated with these are beds in which concretions have not been developed (No. XI).

IX. Spherical nodules separated from the powdery matrix.

X. Hard, platy, fetid, concretionary limestones associated with the above. Well-preserved fossils on the surfaces.

XI. Soft, fetid, greasy, fine-grained, well-bedded, rather massive brown rock. Many fossils as hollow casts.

	IX.	X.	XI.
Insoluble residue	1·23	3·01	1·80
Water, organic matter, etc.	tr.	tr.	1·00
FeO, etc.	0·18	0·60	0·75
$CaCO_3$	89·23	82·91	56·00
$MgCO_3$	9·60	13·65	40·06
Totals	100·24	100·17	99·61
Calcite	77·80	66·66	8·31
Dolomite	21·03	29·90	87·75

Fulwell Quarries, near Sunderland.—XII. Spherical concretions, measuring about an inch and a half in diameter.

Sections of the concretionary growths show very little structure. If stained, rounded specks and fragments of dolomitic aggregates with included impurities are seen embedded in a dense, finely-crystalline, calcareous mass. The whole slide is frequently dark with ferruginous and organic material.

XIII. Yellow powdery matrix associated with the above, occupying the spaces between the concretions.

XIV. Aggregates of small concretions, about the size of peas.

XV. Yellow powdery matrix, occupying the spaces between the above. It can be washed away, or blown away with ease when dry.

XVI. The 'Great Marl-Bed,' underlying the concretionary series. A brown, friable marly rock. It shows traces of concretionary action where it adjoins the overlying beds, but lower down the concretionary action has been entirely arrested.

A section shows patches of allotriomorphic calcite-grains arranged in irregular streaks in the dolomite, from which the calcite is well separated. The dolomite develops rhombic outlines where it projects into the calcite. The slide is full of ferruginous and dirt inclusions; and quartz and tourmaline-crystals can also be seen. (See Pl. XXXVI, fig. 5.)

	XII.	XIII.	XIV.	XV.	XVI.
Insoluble residue	1·26	2·65	1·42	4·11	5·02
Fe_2O_3, etc.	0·45	1·26	0·47	1·22	2·41
$CaCO_3$	90·35	55·37	88·13	55·62	55·69
$MgCO_3$	7·90	40·97	10·22	39·81	35·80
SO_3	0·21	0·23	tr.	tr.	tr.
Totals	100·17	100·48	100·24	100·76	98·92
Calcite	80·95	6·59	75·96	8·23	13·07
Dolomite	17·30	89·75	22·39	87·20	78·42

Byer's Quarry, near Marsden.[1]—Most of this quarry consists of well-bedded, hard, calcareous, more or less distinctly

[1] Byer's Quarry is the chief locality for the fauna of the Upper Limestones. The 'bluestones' here are reputed to be the purest calcite in the district.

concretionary 'bluestones.' Towards the top of the quarry some bands of a friable brown material (so-called 'marl') appear interbedded with the hard rock. This 'marl' passes directly, and with every gradation, into the 'bluestone.' I have seen lumps of 'marl' with centres of 'bluestone.'

XVII. Thinly and evenly-bedded, brown, friable material. When dry it crumbles into a fine powder, of which 99·45 per cent. passes through a sieve of 240 meshes per linear inch, leaving a small residue (No. XVIII). Fossils occur as perfect impressions, including mollusca, foraminifera, and plant-remains.

XVIII. The residue from the above.

XIX. 'Bluestone.' Fine-grained, grey, very hard, calcareous rock. Fossils occur as obscure casts.

	XVII.	XVIII.	XIX.
Insoluble residue	0·27	0·25	0·16
MnO_2	0·61	tr.	tr.
Fe_2O_3, etc.	0·59	2·20	0·19
$CaCO_3$	56·44	56·11	98·04
$MgCO_3$	42·54	42·48	1·43
Totals	100·45	101·04	99·82
Calcite	5·79	5·54	96·34
Dolomite	93·19	93·05	3·13

Flexible Limestones and Similar Beds.

XX. Marsden.—Thinly-bedded, typical Flexible Limestone. No fossils.

XXI. Hesleden Dene.—A thinly-bedded, flaggy, fairly-compact, yellow rock. No fossils.

XXII. West Hartlepool Waterworks, from well-sinkings at a depth of 49 feet A flaggy, extremely hard, rather absorbent, yellow rock. No fossils.

A section shows very small and irregular dolomite-grains, yellow with ferruginous impurities. Calcite occurs locally. The quartz fills much of the space between the dolomite-grains, which in places develop rhombic outlines where they project into it. It may be of secondary origin, or may be a recrystallized residue.

	XX.	XXI.	XXII.
Insoluble residue.	6·70	3·16	42·65 (89·71 % SiO_2)
Fe_2O_3, etc.	1·48	0·72	2·35
$CaCO_3$	50·37	54·96	31·78
$MgCO_3$	41·71	40·94	23·70
SO_3	0·11	0·17	tr.
Totals	100·37	99·95	100·48
Calcite	0·71	6·22	3·57
Dolomite	91·37	89.68	51·91

Upper Shell-Limestones.

Hesleden Dene.—The highest part of the reef.

XXIII. A friable, bedded, very porous, yellow rock, associated with powdery material. Fossils scanty, and somewhat obliterated.

XXIV. A bedded rock similar to the above, but the powder largely removed and the rock slightly segregated. It shows much internal deformation. Fossils plentiful in the less compacted parts.

XXV. Bedded, partly massive, yellow rock, closely associated with the highest Shell-Limestones. It is full of hollow stellate cavities. No fossils.

A stained section shows it to be a fine-grained oolite; the concentric structures are almost masked, owing to recrystallization of the dolomite. The nuclei of the oolites are finely-crystalline dolomite-aggregates dark with impurities. Calcite occurs disseminated through the slide.

	XXIII.	XXIV.	XXV.
Insoluble residue	0·31	0·27	0·74
Fe_2O_3, etc.	0·25	0·39	0·23
$CaCO_3$	54·40	59·09	54·71
$MgCO_3$	45·55	40·05	45·06
SO_3	tr.	0·71	0·06
Totals	100·51	100·51	100·80
Calcite	0·05	11·41	1·06
Dolomite	99·90	87·73	98·71

XXVI. Castle Eden Dene.—Ivy Rock section. A thinly-bedded, very porous and friable, yellow rock with casts of small fossils. It underlies a typical bryozoonal dolomite.

XXVII. Blackhall Rocks. — A large-grained pea-oolite, overlying the Shell-Limestone conglomerate.

A section shows large concentric oolites surrounding nuclei of small dolomite-aggregates. The matrix of the oolites shows a good deal of calcite. The concentric material is practically pure dolomite, but contains specks of deeply-staining calcite. (See Pl. XXXVII, fig. 4.)

XXVIII. Blackhall Rocks.—Shell-Limestone conglomerate. A rock apparently very largely made up of bryozoa of the genus *Thamniscus*, the traces of which are almost obliterated.

	XXVI.	XXVII.	XXVIII.
Insoluble residue	0·21	0·57	0·29
Fe_2O_3, etc.	0·23	0·39	0·17
$CaCO_3$	55·17	64·66	54·16
$MgCO_3$	45·04	34·57	45·75
SO_3	0·11	tr.	tr.
Totals	100·76	100·19	100·37
Calcite	1·55	23·50	0·00
Dolomite	98·66	75·73	99·91

Ryhope Asylum Quarry.—XXIX. 'Gasteropod-reef.' A friable rock, occurring in flaggy masses over a limited area. The uncompacted portions exhibit crowded masses of fossils, including gasteropods, *Chiton* plates, *Nautilus*, valves of *Bakevellia*, *Arca*, remains of bryozoa, etc. All the organisms are encrusted with a fine coating of dolomite.

XXX. Underlying the above. A hard, white, highly-compact and crystalline rock, occurring in large irregular masses. Fossils are to a great extent obscured, but large Fenestellids are seen.

	XXIX.	XXX.
Insoluble residue	0·22	0·47
Fe_2O_3, etc.	0·44	0·37
$CaCO_3$	55·14	55·37
$MgCO_3$	44·69	44·43
SO_3	0·09	tr.
Totals	100·58	100·64
Calcite	1·93	3·68
Dolomite	97·90	95·12

Easington Colliery.—A quarry on the eastern slope of the reef. The Shell-Limestone has here undergone considerable segregation, and a small development of cellular rock is seen.

XXXI. Normal unaltered Shell-Limestone. A rather friable white rock, almost entirely made up of bryozoa, small *Strophalosia*, and other reef-organisms.

A stained section indicates that the organisms, especially the bryozoa, are very highly dolomitized, and show a cryptocrystalline structure. The matrix is chiefly dolomite, highly contaminated with dirt-inclusions, but also shows a good deal of calcite arranged along definite lines. In the material filling the cells of the bryozoa clear crystals of both dolomite and calcite are seen. (See Pl. XXXVI, fig. 3.)

XXXII. Adjoining the above, and passing imperceptibly into it. Hard, coarsely-crystalline, irregularly-segregated, white rock. Fossils are almost entirely obliterated; but, on careful examination, traces of Fenestellids can be detected.

XXXIII. Occupying spaces in, and closely associated with the above. A soft, brownish, incoherent material, crumbling when dry to a fine powder. About 99 per cent. of this passes a sieve of 240 meshes per linear inch.

XXXIV. Residue obtained on riddling the above.

XXXV. Powder similar to XXXIII, but yellow in colour, from another part of the quarry.

XXXVI. Residue obtained on riddling the above.

	XXXI.	XXXII.	XXXIII.	XXXIV.	XXXV.	XXXVI.
Insoluble residue	0·20	0·08	1·14	2·28	1·92	0·50
Fe_2O_3, etc.	0·28	0·13	0·69	1·11	1·04	0·34
				MnO_2 0·21		
$CaCO_3$	55·86	96·64	53·69	71·60	53·80	91·92
$MgCO_3$	44·54	3·39	44·71	25·42	43·39	8·13
SO_3	0 16	0·29	tr.	0·34	tr.	tr.
Totals	101·04	100·53	100·23	100·96	100·15	100·89
Calcite	2·83	92·61	0·46	41·34	2·14	82·25
Dolomite	97·57	7·42	97·94	55·68	95·05	17·80

Calcareous Shell-Limestones (Tunstall and Beacon Hills).

The upper part of Tunstall Hill at the southern end consists of a brown, coarsely-crystalline, calcareous rock. From a part of the hill now largely quarried away, Kirkby obtained a rich and beautiful series of fossils.[1] The rock occurs in large irregular masses, and changes through partial decalcification into a dark-brown, friable, powdery material, enclosing cavities lined with a white mineral allied to ankerite. This material shows much internal deformation, and the decalcification is accompanied by progressive obliteration of the fossils.

Irregular patches and vein-like masses of a similar brown calcareous Shell-Limestone occur in the knoll of Beacon Hill, but the rock is more largely altered by decalcification. In both places the rock occasionally assumes a radiating concretionary structure, and is intimately associated with the dolomitic Shell-Limestone. It weathers in small fragments very differently from the dolomite.

Tunstall Hill. — XXXVII. Hard brown crystalline rock. Full of bryozoa and other fossils. The larger fossils are formed of brown calcite, the smaller of a loose brown manganiferous powder.

XXXVIII. Brown, partly decalcified material. Fossils obliterated.

XXXIX is closely associated with XXXVII. A very hard, white, dense Shell-Limestone dolomite, retaining little trace of fossils.

Beacon Hill.—XL. Dark-brown Shell-Limestone. It is partly decalcified, and the fossils are largely obliterated.

	XXXVII.	XXXVIII.	XXXIX.	XL.
Insoluble residue	0·10	0·19	0·24	0·28
Fe_2O_3, etc.	0·12	0·53	0·63	0·79
MnO_2	0·66	6·47	—	5·88
$CaCO_3$	98·08	91·17	55·02	89·24
$MgCO_3$	1·52	1·80	44·01	4·11
SO_3	tr.	tr.	0·33	0·18
Totals	100·48	100·16	100·23	100·48
Calcite	96·27	89·03	2·62	84·35
Dolomite	3·33	3·94	96·41	9·00

[1] Now in the Newcastle Museum. The late Mr. J. W. Kirkby considered Tunstall Hill the richest locality in England for the Permian gasteropods.

Lower Shell-Limestones.

Claxheugh Quarry.—XLI. Crinoid-stems freed from their matrix. A section of the crinoidal rock shows it to be full of remains of organisms which are almost completely dolomitized, and have a cryptocrystalline structure. The matrix consists of closely-packed allotriomorphic dolomite-grains full of inclusions. Staining takes place locally, showing the presence of a very small quantity of calcite; but no well-defined grains are seen. Brown patches of impurities occur. (See Pl. XXXVI, fig. 2.)

Ford Quarry, Claxheugh.—A development of cellular rock occurs here on the flank of the reef, very closely associated with Shell-Limestone.

XLII. Very fine, incoherent, crystalline powder filling the angular cavities.

XLIII. The hard cellular matrix enclosing the above powder.

	XLI.	XLII.	XLIII.
Insoluble residue	3·65 [1]	2·41	2·04
Fe_2O_3, etc.	0·32	0·65	0·45
$CaCO_3$	52·26	54·21	93·35
$MgCO_3$	43·81	43·53	5·08
Totals	100·04	100·80	100·92
Calcite	0·10	2·39	87·31
Dolomite	95·97	95·35	11·12

Blackhall Colliery Sinking.—Towards the base of the Shell-Limestone.

XLIV. This is an extremely-fossiliferous whitish rock, with a fully-developed reef-fauna, including *Spirifer alatus*. The shells are represented by a loose white powder.

XLV. Highly-fossiliferous yellowish rock, completely built up of specimens of *Camarophoria globulina*, *Pecten pusillus*, and other forms.

XLVI. Shell-substance of a *Productus horridus*. White, rather powdery material, retaining in part the original shell-structure.

XLVII. Shell-substance of an *Arca tumida*. White, very incoherent powder, partly preserving the shell-structure.

XLVIII. The mould filling the interior of XLVI. It was half filled with a compact, pale-yellow rock, enclosing remains of ostracods and other small forms.

	XLIV.	XLV.	XLVI.	XLVII.	XLVIII.
Insoluble residue ...	0·45	1·71	0·11	0·28	1·45
Fe_2O_3, etc.	0·30	0·47	0·28	0·56	0·67
$CaCO_3$	55·44	55·69	56·02	53·87	54·41
$MgCO_3$	43·94	42·98	43·77	45·05	43·17
SO_3	0·14	0·14	tr.	tr.	tr.
Totals	100·27	100·99	100·18	99·76	99·70
Calcite	3·13	4·52	3·91	0·24	3·01
Dolomite	96·25	94·15	95·88	98·68	94·57

[1] One of the crinoid ossicles was partly silicified.

Hartlepool, Warren Cement-Works Boring.—Middle Beds, associated with a mass of anhydrite and gypsum.

XLIX. Very hard and compact dark-grey rock, embedded in and impregnated with anhydrite, and containing stellate aggregates of anhydrite-crystals.

A stained section reveals the merest trace of calcite. The anhydrite occurs in big clear radiating crystals, often containing slight dolomite-inclusions. The dolomite consists of closely-compacted allotriomorphic grains with included impurities. It does not develop rhombic outlines where it projects into anhydrite. (See Pl. XXXVII, fig. 1.)

L. Beneath the anhydrite mass. Dark-grey rock with specks of gypsum, but no anhydrite. Traces of gasteropods, *Strophalosia*, and bryozoa occur.

Stained sections reveal large dolomite-grains, both allotriomorphic and idiomorphic, with faint dirt-inclusions—chiefly towards the centres. Very little calcite is present; but an occasional allotriomorphic crystal occurs, and it is seen separating out in strings. Another more highly-gypsiferous section is made up of very small allotriomorphic dolomite-grains, dark with inclusions. Gypsum occurs in irregular patches, while the dolomite-crystals become very much larger and clearer, and develop rhombic outlines where they project into or lie in gypsum. (See Pl. XXXVI, fig. 1.)

	XLIX.	L.
Insoluble residue	1·93	2·32
Water, etc.	—	0·61
FeO, etc.	0·75	0·83
$CaCO_3$	38·30	49·33
$MgCO_3$	32·16	39·50
$CaSO_4$	27·85	7·58
Totals	100·99	100·17
Calcite	0·02	2·30
Dolomite	70·44	86·53

Bedded Middle Series, on the Eastern side of the Shell-Limestone.

The structure of these beds is now almost completely masked by the changes which they have undergone. A considerable mass of thickly-bedded dolomitic rock occurs beneath the Flexible Limestone in the coast-section between Ryhope and Sunderland, in which spongy calcareous structures are developed only to a moderate degree. Otherwise I have seen but three very definite patches of original material, all of which were analysed.

The lowest part of this division at Trow Rocks includes a considerable extent of the true 'cellular rock,' resting directly upon well-bedded Lower Limestones. The line of demarcation

between these has been described by Dr. Woolacott as a plane of thrusting.[1] Between here and Marsden the upper part is associated with more or less definite 'breccia-gash' phenomena.[2] The gashes consist of fallen masses, both of segregated calcareous fragments, and of fragments of the overlying concretionary and bedded Upper Limestones mixed with dolomitic powder, collapsed into fissures and cracks formed in the undulating surface of the segregated and altered Middle Beds.

Along most of the coast-section where this division is exposed, the powdery dolomite has been washed away: consequently there has ensued collapse and brecciation of the remaining calcareous material, resulting in a bewildering series of unfossiliferous breccias which flank the eastern side of the reef. These calcareous breccias become in parts recemented, or have their interstices filled with superficial matter washed in. In some cases, this material consists of powdery dolomite from other parts of the rock, simulating a reverse type of 'breccia' to that of the true cellular rock, where the enclosed fragments are always more dolomitic than the cementing matrix.

The thickness of these beds in the Marsden area is about 120 feet. No fossils, except plant-remains, are known from the unaltered portions.

Trow Rocks, near South Shields.—A patch of unchanged rock, about 30 feet wide and 20 feet thick, surrounded and overlain by hard, calcareous, cellular material which is quarried in great masses for pier-works at the mouth of the Tyne. Fine lines of incipient cellular structure are to be seen along some of the bedding-planes of the unaltered rock, and the mass merges laterally with every gradation into the adjacent hard, massive, cellular rock. The whole rests upon well-bedded Lower Limestone (No. LIV), very similar in composition to the unaltered Middle Beds.

LI. Original, very thinly and evenly-bedded, porous rock, enclosing flattened cavities, after a soluble constituent, along the bedding-planes. Plant-remains occur. This rock is soft enough to crush between the fingers.

The next two examples were taken where the above-described bed passes into the hard cellular rock. They consist of angular fragments of all sizes, of very incoherent yellow and white powder, cemented in a hard, grey, calcareous matrix.

LII. The powder removed from the cavities. Practically all of it passes through a sieve of 240 meshes per linear inch.

[1] 'On a Case of Thrust & Crush-Brecciation in the Magnesian Limestone (County Durham)' Mem. Univ. Durham Phil. Soc. No. 1, 1909; and 'The Stratigraphy & Tectonics of the Permian of Durham (Northern Area)' Proc. Univ. Durham Phil. Soc. vol. iv, pt. 5, 1912.

Horizontal pressures acting from without would doubtless have an exaggerated effect upon such a rock as the Magnesian Limestone, weakened, first by leaching-out of sulphates, and secondly by washing-away of powdery dolomite. Such effects would not, in my opinion, be easy to distinguish from the internal displacements of the formation incidental to these changes.

[2] G. A. L. Lebour, 'On the Breccia-Gashes of the Durham Coast, &c.' Trans. N. Eng. Inst. Min. Eng. vol. xxxiii (1883) p. 165.

LIII. The calcareous investing matrix, removed by washing the powder from it.

LIV. The Lower Limestone underlying the above beds. A yellow, thinly-bedded, compact, rather fissile rock. No definite fossils.

	LI.	LII.	LIII.	LIV.
Insoluble residue	2·31	2·55	2·69	0·43
Fe_2O_3, etc.	0·46	0·41	0·78	0·83
$CaCO_3$	54·66	53·15	81·88	55·17
$MgCO_3$	43·06	44·46	15·50	44·37
Totals	100·49	100·57	100·85	100·80
Calcite	3·40	0·22	63·43	2·35
Dolomite	94·32	97·39	33·95	97·19

Coast-section near Horden Burn.—A patch of original rock about 20 feet thick, extending for 70 yards at the base of the cliff. It underlies 40 feet of calcareous breccias, and at the southern end graduates into the calcareous beds. The first sign of alteration is the infilling of the empty stellate spaces with calcite, and the development of incoherent powdery material with obliteration of the original rock-structure. Then incipient spongy calcareous structures begin to appear in the bedded rock, and the powder becomes washed out. No fossils seen.

LV. Fine-grained, soft, white, well-bedded, 'soapy' rock, full of clean cavities arranged in stellate aggregates, with very small lenticular cavities.

LVI. Fine-grained, yellow, fetid, 'soapy' rock without cavities. It is massive in part, and closely associated with the above.

LVII. Hard segregated material, developed in the above rocks towards the southern end of the section.

	LV.	LVI.	LVII.
Insoluble residue	1·99	3·14	2·35
Fe_2O_3, etc.	0·38	0·61	0·26
$CaCO_3$	53·13	52·80	82·86
$MgCO_3$	44·24	43·86	14·58
Totals	99·74	100·41	100·05
Calcite	0·46	0·58	65·50
Dolomite	96·91	96·08	31·94

Bedded Middle Series, on the Western side of the Shell-Limestone.

These beds, owing to greater denudation in the north, are confined to the south-western portion of the Durham Permian, where they cover a considerable extent of country. They are nearly

everywhere highly changed, being thereby distinguishable from the underlying Lower Beds. Original patches occur in most of the sections, and yield a scanty but very constant fauna. Unaltered beds are frequently massive, and very regularly stratified. The segregations often follow the lines of stratification; and subsequent removal of the powdery dolomite accentuates the appearance of bedding, leading to irregularity and brecciation.

Castle Eden Dene, near Devil's Bridge.—LVIII. Fine-grained, well-bedded, friable, yellow, slightly fetid rock. Well-preserved casts of *Astarte vallisneriana* and other fossils occur.

Castle Eden Dene, near White Rock.—LIX. Thinly-bedded, fine-grained yellow rock, interstratified with segregated material. Flat hollow spaces occur along the bedding-planes, with casts of serpulæ, ostracods, and small bivalves.

Sections of both these rocks (LVIII & LIX) exhibit loosely-compacted allotriomorphic dolomite-grains, with included matter. Staining shows a faint coloration round the margins of the grains. A faint general stain suggests that the inclusions are largely calcite, a surmise which is confirmed on examination with a higher power. Occasional calcite-groups occur.

	LVIII.	LIX.
Insoluble residue	0·16	0·05
Fe_2O_3, etc.	0·12	0·41
$CaCO_3$	54·50	55·14
$MgCO_3$	45·60	44·93
SO_3	tr.	0·10
Totals	100·38	100·63
Calcite	0·21	1·65
Dolomite	99·89	98·42

Tuthill Quarry, near Haswell.—A small patch of original rock occurs near the base of a very big quarry-section of highly-segregated beds. Powdery material has largely disappeared towards the upper part of the section. Its position cannot be far above the top of the Lower Beds. Casts of the usual fossils occur in plenty.

LX. Extremely-friable yellow oolite.

LXI. Extremely-friable, fine-grained, non-oolitic rock, in rather massive beds.

	LX.	LXI.
Insoluble residue	0·02	0·12
Fe_2O_3, etc.	0·57	0·36
$CaCO_3$	56·24	55·35
$MgCO_3$	44·05	44·75
SO_3	0·07	0·02
Totals	100·95	100·60
Calcite	3·80	2·07
Dolomite	96·49	98·03

Lower Limestones.

Blackhall Colliery Sinking.—A yellow, well-bedded, friable, nodular rock, with loose powdery material between the harder nodular parts. No fossils.

LXII. The fine incoherent powder.

LXIII. The harder nodular portion, freed from the above by washing.

	LXII.	LXIII.
Insoluble residue	0·21	0·18
Fe_2O_3, etc.	0·42	0·13
$CaCO_3$	54·95	55·43
$MgCO_3$	45·27	45·05
Totals	100·85	100·79
Calcite	1·05	1·80
Dolomite	99·17	98·68

LXIV. Near the top of the Lower Limestone. Yellowish-white, well-bedded, rather soft rock with carbonaceous partings. Comminuted bryozoa and plant-fragments occur.

LXV. A very white, dense, compact, fine-grained, bedded rock without cavities. No fossils.

LXVI. Near the base of the Lower Limestone. Hard, dark-grey, compact bedded rock, with irregular carbonaceous partings. Cavities, lined with a few small crystals of pyrite and calcite, occur along the bedding-planes. No fossils.

Stained sections of the last two rocks show small, closely-compacted, allotriomorphic dolomite-grains, dark with inclusions of ferruginous matter, pyrite-grains, etc. A general stain over No. LXVI shows the presence of a good deal of calcite, gathered round the margins of the dolomite-aggregates, and also along straight lines passing in various directions. No. LXV shows less calcite, but the mineral is similarly distributed.

	LXIV.	LXV.	LXVI.
Insoluble residue	0·15	0·12	1·01
Fe_2O_3, etc.	0·59	0·22	2·22
$CaCO_3$	55·01	55·29	54·94
MgCO	44·78	45·18	42·35
SO_3	0·08	0·03	0·14
Totals	100·61	100·84	100·66
Calcite	1·70	1·50	4·52
Dolomite	98·09	98·97	92·77

Thickley Quarry, near Shildon.—LXVII. A smoke-grey, fine-grained, compact rock enclosing numerous well-preserved fossils, such as *Productus*, *Spirifer*, etc. This calcareous rock is regularly bedded, with little trace of internal movement.

LXVIII. Shell of *Productus* from the above-described rock.

It is preserved exactly as in a normal limestone, and has a fissile laminated structure.

LXIX. About 5 feet above No. LXVII. Thinly-bedded, brown, rather compact dolomite, with traces of plant-remains. Occasional badly-preserved casts of fossils occur, and evidences of internal movement are apparent.

Raisby Hill, near Coxhoe.—LXX. Near the base of the Lower Limestone. A rather nodular, irregular, grey and brown bed. Hackly surfaces and other traces of internal solution and disturbance are seen. Fossils occur sparingly, preserved as No. LXVIII, also plant-remains.

Sherburn Hill.—LXXI. About 10 feet above the Marl Slate. A well-bedded yellow, rather porous, hard rock enclosing a few hollow casts of ostracods and bivalves, with obscure plant-remains.

	LXVII.	LXVIII.	LXIX.	LXX.	LXXI.
Insol. residue..	0·63	nil	4·15	1·68	2·00
Fe_2O_3, etc.	2·66	0·30	1·93	0·37	1·23
$CaCO_3$	95·94	98·35	53·32	97·01	55·22
$MgCO_3$	1·49	1·15	40·43	1·46	42·01
SO_3	0·08	tr.	0·15	tr.	tr.
Totals	100·80	99·80	99·98	100·52	100·46
Calcite	94·17	97·02	5·19	95·27	5·19
Dolomite	3·26	2·48	88·56	3·20	92·04

Piercebridge. Riverside section.—LXXII. Brown, rather friable, well-bedded rock, retaining traces of empty stellate cavities. No fossils.

High Coniscliffe-on-Tees.—LXXIII. Soft, yellowish-brown, friable, small-grained oolite. No fossils.

Midderidge Quarry. A few feet above the Marl Slate.—LXXIV. Well-bedded, dark, compact rock. It is traversed by thin calcite-veins, and shows some internal distortion. Twigs and fruit of *Ullmannia* are plentiful.

	LXXII.	LXXIII.	LXXIV.
Insoluble residue	0·69	0·23	3·48
Fe_2O_3, etc.	0·48	0·31	0·63
$CaCO_3$	54·69	60·30	54·33
$MgCO_3$	45·15	39·40	41·50
Totals	101·01	100·24	99·94
Calcite	0·93	13·39	4·91
Dolomite	98·91	86·31	90·92

Marl Slates.

Blackhall Colliery Sinking.—LXXV. A dark flaggy rock, passing upwards into the Lower Limestone.

LXXVI. The typical dark-grey, soft, bituminous rock with fish-remains.

	LXXV.	LXXVI.
Insoluble residue	12·48	41·18
Bituminous matter	0·44	13·92
$FeCO_3$	0·67	0·56
Al_2O_3	5·15	1·87
$CaCO_3$	48·60	22·91
$MgCO_3$	32·26	17·86
$CaSO_4$	0·46	1·83
Totals	100·06	100·13
Calcite	10·19	1·65
Dolomite	70·67	39·12

III. Evidence bearing upon Dolomitic Deposition and on the Dolomitization of the Shell-Limestone.

I do not intend to raise any theoretical questions regarding the origin of dolomites, in a paper intended to be purely a record of observations. I may say, however, that during the course of the present work the following considerations have suggested themselves as evidence supporting the view of the direct deposition of the greater part of the dolomite in the bedded Magnesian Limestones.

(i) The general uniformity in dolomitic composition over wide areas of most parts of the formation, as indicated by analyses of those portions that have escaped segregation. In the dolomitic Lower Beds fossils are either absent, or only very sparingly present. In some of the unaltered Middle Beds on the in-shore side of the reef small forms occur in plenty. It is only in a few of the Upper Beds that *Schizodus*, *Liebea*, and *Chondrites* occur in quantities, approaching a rock-building character. In very few of these cases do the organisms themselves seem to have become dolomitized, the casts of the fossils being represented by clean hollow cavities, in contrast with the dolomitic powder which fills the shell-spaces in the Shell-Limestone. When rapidly covered up with sedimentary material, the organisms seem to have escaped dolomitization. The perfect preservation in pure dolomites of casts of such minute forms as ostracods shows that the probability of a wholesale obliteration of organisms through dolomitization having taken place in these bedded dolomites, is a very remote one. No trace of 'patchy dolomitization,' except in parts of the reef, has been observed.

(ii) Those beds that enclose hollow spaces, which I endeavoured to show[1] were left by crystalline anhydrite-aggregates, consist in every case of nearly pure dolomite. If dolomitization had been effected through a secondary process, it would seem probable

[1] 'On a Mass of Anhydrite in the Magnesian Limestone at Hartlepool' Q. J. G. S. vol. lxix (1913) pp. 196–96.

that these thin plate-like aggregates would become eroded or dissolved up again during the process. On the contrary, the edges of these crystal impressions still retain a knife-like sharpness. In these beds, which are very widespread, especially in the Upper and Middle Series, a rapid deposition of anhydrite seems to have taken place concurrently with the formation of almost pure dolomite, in which the structures became embedded.

(iii) Towards the lower parts of the thick anhydrite-mass at Hartlepool, where carbonates begin to appear, first in faint streaks and lower down in thicker bands, their composition was found to be that of a pure dolomite. If the dolomitization were of a secondary nature, one must presuppose the same process to have been in action when the conditions had so changed that a thick mass of anhydrite was being deposited, in order to convert every fragment of carbonate into dolomite.

(iv) Stained sections of the oolites in the Magnesian Limestone indicate that in every case where the structures have remained unchanged,[1] the concentrically-arranged material surrounding the nuclei is practically pure dolomite. The frequent departure from the dolomitic proportions in bulk analysis of many oolites is due to the nuclei of the structures being of calcite, but whether this calcite is in every case original or not would be hard to say. I see no reason to assume that these dolomitic oolites originated otherwise than in the simplest conceivable manner, through deposition round nuclei moving under wave or current-action. No organic structures seem to have interfered with their perfectly regular growth.

None of these considerations would, however, preclude the possibility that dolomitization of the calcareous material took place either at the instant of precipitation, or during its passage through the waters of the sea.

Carbonate of lime must have been present in the waters of the Permian sea, in order to supply the organisms of the reef with the large quantities required by them. It is conceivable, owing to the restricted distribution of the fauna, that only a portion of the carbonate would be withdrawn in this manner, leaving the remainder to form a direct precipitate. The conditions prevailing in the Permian sea seem, then, to have brought about the direct sedimentation of dolomite.

At the same time, there is every reason to suppose that extensive secondary dolomitization was taking place in the submerged portions of the Bryozoan Reef, resulting in the ultimate conversion of the greater portion of the Shell-Limestone reef into a mass of practically pure dolomite.[2] Both analysis and microscopical examination show the material representing the tests

[1] Both oolites and their matrix sometimes become more or less completely calcified or silicified.

[2] The reef in Durham extends over a distance of more than 20 miles, with an average width of about 2 miles, and an original thickness of about 300 feet.

of the organisms in the reef to be dolomite. The loose and incoherent nature of much of this material, however, indicates that, in the case of some of the larger shells, the process may have been a selective and partly incomplete one, the remaining calcite having been dissolved out.

The Shell-Limestone reef must have been a very porous and loosely compacted structure. The matted masses of bryozoa formed a sort of protective roof, preventing the dolomitic sediment from filling up the interstices of the reef. The larger shells are frequently seen to have been only filled up in part with a dolomitic mould, consisting of decomposed fragments of the smaller organisms and other reef-débris, the material having been apparently injected into them in a pasty condition. It appears that the dead and decomposing remains of bryozoa were as susceptible of dolomitization as are the calcareous algæ of recent atoll-reefs. At the present time, in the less compacted portions of the reef fossils are admirably preserved; while, in the compacted portions, the rock frequently becomes a hard, clean, structureless, crystalline dolomite.

It is certainly a curious fact that large portions of the reef, notably at Tunstall Hill, should have retained their calcareous character, the more so, that these portions happen to be more highly manganiferous. The manganese dioxide seems to be original; but it is not easy to see in what way it can have exerted any influence, in retarding or arresting the dolomitization of portions of the reef.

The weathered surfaces of these calcareous Shell-Limestones exhibit the utmost profusion of bryozoa and other forms, and there is nothing to indicate any change in the fauna, except the presence of a few rare forms which do not occur elsewhere. Gasteropoda, especially Chitonidæ, have occurred here in unusual profusion. These may, however, indicate a shallowing of the water over the reef, and thereby some connexion with the escape from dolomitization.

IV. Segregation and Dedolomitization.

The calcareous segregations observable in the Magnesian Limestone may be relegated to two main orders.

(1) The true spheroidal concretionary structure, chiefly developed on a fairly definite horizon in the lower part of the Upper Limestones, but also to a slight extent elsewhere. The opinion that these structures are penecontemporaneous with the deposition of the beds has been generally held since Sedgwick's time. The curious spheroidal, botryoidal, radiating, and other forms taken up by the calcareous material are due to distortion of the calcite-crystals, apparently under the influence of oily or bituminous organic matter. This matter may have originated through decay of the organisms in the underlying adjacent Shell-Limestone reef, with which the concretionary beds are rather closely associated.

The calcite and dolomite in these concretions and their matrix are, as a rule, less completely separated than in the concretions of the next order.

Fossils are generally well preserved in or upon the calcareous segregations, but they exist only as empty casts in the adjacent dolomitic beds.

(2) Irregular segregations, presumably contemporaneous with, and subsequent to, the removal of sulphates from the rock. Large tracts of Middle and Upper bedded rocks are changed in this way.

Fossils are in most cases entirely obliterated—in the calcareous portions through recrystallization, in the dolomitic portions through the washing-down and degradation of the loose powdery material.

The fine powdery matrix [1] is very similar in both types of concretions. Analysis indicates the proportion of dolomite in it to range from about 87 to 90 per cent. in the first type, and from about 95 to 98 per cent. in the second type. In the first type the material is homogeneous throughout; but in the second type the larger residue remaining after riddling is more calcareous, approaching the composition of the segregated portions of the rock.

A microscopic examination of the small residue, which remains after riddling the very fine material through a sieve of 240 meshes to the linear inch, shows the nature of the powdery matrix of the concretions to be as follows:—

The greater part consists of aggregates of minute crystalline dolomite-grains; in many cases, they occur as clear, colourless or yellowish, rhombic crystals. Some of the aggregates are coated and cemented together with a dark dendritic encrustation of manganese dioxide. Mixed with these occur much larger clear calcite-grains, often in the form of doubly-terminated scalenohedral crystals. Some are lying clear in the mass, singly or in aggregates. Others are coated with, and partly hidden by, the dolomitic grains, as though they were in the act of rejecting these during growth. Siliceous and other residues lie loose in the mass.

No analyses seem to have been made of the gypsiferous beds bored through in the Seaton-Carew or other similar borings, and all the carbonates that I examined from a boring under a mass of anhydrite at Hartlepool were dolomites. The question as to whether in former periods, in the presence of saturated or supersaturated solutions of calcium sulphate, the dolomite was as stable as it is under present conditions, or whether gypsum in any form can have assisted the segregatory migration of calcareous particles, remains a problematical question.[2]

[1] The German term Dolomitgruss or Dolomitasche is applied to a similar material consisting largely of minute dolomite-rhombs. I have seen it in cavities in rauchwacke in the Gera district, but never approaching the extent to which it is developed in Durham. German investigators seem to regard it as a residue left after solution of gypsum.

[2] Calcareous replacement of dolomite to an abnormal extent is often visible in the vicinity of faults or other planes of movement, and would seem to

A certain segregation of gypsum is apparent in these rocks, where it often occurs in small isolated masses.

Edward Wilson[1] quotes two evidently reliable analyses of Magnesian Limestones associated with gypsum, at depths of 154 and 193 feet respectively below the salt-bed: one is dolomitic, and the other calcareous. The latter may be in the concretionary series; but, in any case, it seems to point to a calcareous segregation prior to the removal of sulphates from the rock.

In every case in these borings, the rock seems to have been hard and compact through impregnation with gypsum, and no mention of powdery or 'marly' material is made in the records.

The formation of botryoidal concretions can scarcely be taking place at the present day, but those of the second type may very probably be still in process of formation, and certainly mechanical dedolomitization is proceeding apace.

Under existing conditions, the separation of the calcite and dolomite in the Magnesian Limestone seems to be entirely a question of differential solution of these two minerals. I have not been able to trace the slightest evidence of any leaching-out of magnesium carbonate from the dolomite of the rock, leaving calcite behind it. However, the possibility of small quantities of dolomite having been removed by solution is not to be denied. The process is doubtless assisted primarily by the inherent tendency of the constituents of this and other ancient sedimentary rocks to revert to a highly-crystalline condition. A certain loosening of dolomite-grains would take place in such a rock as

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indicate that heat generated by the movement had some effect in assisting the segregation of calcite. It is especially well seen at a small fault cutting the Flexible Limestone, on the coast-section between Ryhope and Sunderland. There is no evidence of contraction, as the bed maintains a uniform thickness; but the dolomite is gradually replaced by calcite, which first appears as calcareous granules along the lines of bedding, associated with a very fine incoherent yellow powder. The granules become more numerous and finally coalesce, until they form a hard mass still retaining the lines of bedding and, to some extent, the fissile nature of the original flexible rock. This hard calcareous rock becomes highly brecciated at the fault-line, and all trace of bedding is thus finally obliterated. All this change from flexible dolomite to a calcareous brecciated mass takes place within a space of 100 feet. The initial and final stages were chemically examined, and the results are tabulated below:—

	Flexible Limestone.	Hard calcareous rock.
Insoluble residue	0·88	1·04
Fe_2O_3	0·61	0·19
$CaCO_3$	55·01	88·56
$MgCO_3$	43·78	10·92
Totals	100·28	100·71
Calcite	2·88	75·55
Dolomite	95·91	23·93

[1] Q. J. G. S. vol. xliv (1888) p. 763.

No. L, merely by the leaching-out of the gypsum which impregnates it.

Incoherent powdery material, of the nature just described, is apparent in nearly every exposure of the Magnesian Limestone in Durham. When developed on an extensive scale, however, it is always closely associated with calcareous segregations. It may be concluded, then, that the main factor concerned in the liberation of the powdery dolomite, is the withdrawal of interstitial calcite from the rock through former processes of segregation and, under present conditions, through the solvent action of percolating water.

The greater solubility of the calcite in contrast with the relative insolubility of the dolomite under ordinary conditions, is clearly indicated by several observable facts:—

(*a*) Geodes lined with large secondary calcites [1] are very frequent in friable dolomitic rocks. The cavities are apparently contraction-effects, and the presence of such calcite-lined cavities is a very certain sign of alteration in the rock.

(*b*) Large doubly-terminated calcite-twins occur embedded in the dolomitic matrix of the concretionary structures at Fulwell, Byer's Quarry, etc.

(*c*) In some compact dolomites in the Lower Limestone, thin calcite-veins traversing the rock are seen on weathered surfaces as channels dissolving out more rapidly than the dolomite which encloses them.

(*d*) The instance of the Knaresborough 'dropping well,' where water passing through a porous dolomitic rock coats objects with a calcareous encrustation. (This instance need, however, scarcely be mentioned; also, it is not in Durham.)

The conditions most favourable to the production of powdery material are those in which a relatively-small quantity of calcite exists disseminated through a highly-dolomitic rock, in which it acts as a binding medium to a large quantity of dolomite-grains. Such conditions are present, to a great extent, in all divisions of the Magnesian Limestone in Durham.[2]

On the other hand, the condition which has allowed the escape of certain patches of the formation from the general process of segregation, collapse, and dolomite-removal which has overtaken so many beds, has been in many cases the local presence of an exceptionally large proportion of dolomite. In other words, on removal of the small quantity of interstitial calcite, the dolomite-grains still remain so closely interlocked that the tendency to collapse and become washed down is overcome. In such cases, the mass of incoherent dolomite-grains may still retain the impressions of enclosed fossils more or less faithfully preserved.

The bedded rocks still enclosing casts of *Astarte vallisneriana* in Castle Eden Dene are theoretically pure dolomites. In certain

[1] Dolomite never occurs thus. I have found nests of small dolomite-rhombs loosely filling rounded cavities in some beds, having seemingly grown in a matrix of gypsum now dissolved away.

[2] A similar feature has been observed by Mr. E. E. L. Dixon in the case of Carboniferous dolomites, Q. J. G. S. vol. lxvii (1911) p. 314.

dolomitic fragments among segregated calcareous beds in Haswell Quarries, Byer's Quarry, and elsewhere, the rock enclosing perfect impressions of shells or even plant-remains is excessively friable. When the material is freshly taken from the quarry, the capillarity of the enclosed water holds the grains together; but, on drying, the mass crumbles to powder at a touch.

The Flexible Limestone of Marsden (No. XX) consists of minute, loosely-compacted dolomite-grains with siliceous and argillaceous residues, and owes its flexibility to movement between the grains.

On a more extensive scale, many of the highly-dolomitic uppermost beds (Hartlepool and Roker Series) have escaped alteration. The quantity of interstitial calcite is so small that very little segregation can take place, and the resulting disturbance of the dolomite is correspondingly slight.

In a sample of Lower Limestone, however, the slight segregation or concentration of calcite, indicated in analysis by a difference of about 0·5 per cent., suffices to release a considerable quantity of dolomite from a nearly dolomitic rock. This specimen (Nos. LXII & LXIII) is from a depth of 725 feet in Blackhall Sinking. The removal of such powdery dolomite has caused much of the nodular structure and internal bending seen in the Lower Limestones at the surface.

The segregated Shell-Limestone at Easington (Nos. XXXI–XXXVI) is of interest, because so numerous are the fossils that, neither in the calcareous segregations, nor in the powdery material, are they completely obliterated—showing that both these materials have resulted from a change in the Shell-Limestone similar to that adjacent to them.

Careful sampling and analysis, and reduction of the results to terms of calcite and dolomite, indicate that the removal in one case of about 2 per cent. of calcite from the rock, in another case apparently the mere recrystallization of the interstitial calcite in the powdery mass, suffices to bring about the collapse of the dolomite-grains, with an all but complete obliteration of the fossils.

It is often difficult to form an opinion regarding the original composition of several now highly-segregated calcareous beds. In some parts of the concretionary series, in Byer's Quarry for instance, segregation has taken place so evenly along the bedding-planes and the powdery dolomite has been removed so gradually, that very little brecciation has resulted from the settling-down of the calcareous material. In such cases, it is easy to assume a highly-calcareous original nature for the rock; but the presence of occasional remaining fragments of uncollapsed dolomite-powder retaining perfect fossil-impressions suggests a different inference.

The original dolomitic nature of such beds probably approximated to that of adjacent beds where the development of concretionary structures has been arrested, as noticed by Prof. E. J. Garwood,[1] by the marly and sandy impurities present in the rock.

[1] 'Origin of Concretions in the Magnesian Limestone of Durham' Geol. Mag. dec. 3, vol. viii (1891) p. 435.

The washing-away of powdery material from the rock entails also the withdrawal of small quantities of calcite, quartz, and other constituents present in it; but the quantity is so small relatively to the dolomite, that the remaining rock is always left in a very much more calcareous condition than before. The somewhat anomalous effect is thus attained, of a partial decalcification resulting in a widespread removal of dolomite and enrichment in calcite of the formation. As already stated, this mechanical removal of powdery dolomite is the only observable process whereby the dedolomitization of the rock on an extensive scale is effected. It is also a very powerful agent in the breaking-down and disintegration of the rock.

The powdery dolomite is generally so extremely fine, that a very feeble current of water would suffice to carry it through the interstices of the rock. In all newly-opened quarries or sections in segregated or cellular beds, the powder can be seen in process of removal. A shower of rain washes it in quantities out of the rock, after which it hangs on the rock-face in large dried masses. The small earth-tremors often felt at Sunderland and elsewhere on such beds are attributed to settling-down consequent upon this removal.

V. The Origin of the Cellular Structures.

The true cellular structures are most conspicuously developed, as already stated, in the cliffs at Trow Rocks near South Shields. They also occur on a much smaller scale at several localities on the eastern slope of the Shell-Limestones (Ford Quarry, Easington Colliery, Down Hill, etc.), where the reef merges into the bedded equivalents on its flank. Every gradation can be traced from the Bryozoan Reef-dolomite, through the cellular rock, to the calcareous segregated fragments which have suffered collapse and brecciation, consequent on more or less complete removal of powdery dolomite.

Before the origin of these structures is discussed, a few of the outstanding features observable on a critical examination of them may be noticed:—

(1) The cementing material is always more calcareous than the enclosed fragments, and is very inconstant in composition.

(2) The fragments are angular, and quite irregular in shape and size.

(3) Bedding or lamination is often apparent in the angular fragments, or is seen on the sides of the cavities whence the powdery material has been removed.

(4) The interior walls of the cells, when emptied, are generally seen to have a rough and irregular surface, as though a later deposit of calcite-grains derived from the enclosed fragment had taken place upon them.

(5) The powdery material differs in no way from that associated with other forms of calcareous segregations, except that, being enclosed in a cell, it has no ready means of escape.

(6) I have never seen what has been termed a 'negative breccia.' On exposed surfaces and near cracks and fissures, the powdery dolomite is generally removed completely from the cells; but, on freshly-broken surfaces, the cavities are always either loosely or compactly filled with powder.

A separation of calcareous material along lines, presumably of tension or weakness, in the Magnesian Limestone frequently leads to an appearance of brecciation. The process in an incipient stage can be seen in many thin sections of dolomitic rocks, showing no trace of brecciation, when stained with Lemberg's mixture, as thin calcareous lines passing in various directions. The calcareous ribs thus induced seem to act as nuclei for further segregation, and gradually to divide up and isolate angular fragments of the rock, which by the withdrawal of interstitial calcite become reduced to an incoherent dolomitic powder. In some cases, I have seen calcareous ribs, obviously of later origin than the main development of the cellular structure, passing straight through both the spongy cellular material and a dolomitic fragment embedded in it.

Many, therefore, if not all of these structures may, in my opinion, be classed under the category of pseudo-breccias.

An alternative view that these angular structures are of clastic origin deserves notice. At the outset, it will be clear that the rock whence they were derived must have been in a very different condition of hardness, through impregnation with gypsum or calcite, from its present condition. The smallest pressure now suffices to reduce to powder either the original unbrecciated bedded rock adjacent to it, or the fragments enclosed in the cells.

A possible mode of origin is some such process as the following. In the Magnesian Limestone found by boring beneath the thick anhydrite-bed at Hartlepool already mentioned, occurred angular breccias of a hard, dense, highly-dolomitic and gypsiferous rock. The fragments were slightly separated, and cemented by secondary gypsum derived from hydration of the overlying anhydrite. This secondary gypsum might become replaced by calcareous material derived from other parts of the rock. A subsequent complete leaching-out of more soluble constituents, including all the gypsum from the enclosed fragments, would result in a calcareous matrix enclosing angular masses of more or less compact dolomite, similar to that which occurs in the typical cellular rock.

VI. The Insoluble Residues.

The residues of so problematical a formation as the Magnesian Limestone merit a special investigation, and only a few points can be mentioned here.

The comparatively large residue found in the dolomite embedded in anhydrite (No. XLIX) is difficult to account for, in view of its absence in the adjacent anhydrite,[1] and would seem to indicate that much of the quartz in the Magnesian Limestone is of non-detrital origin. Certainly, the quartz-grains enclosing pyrite-

[1] Several lumps of anhydrite were dissolved up without any residue being found.

crystals, occurring in this and other residues, can scarcely be detrital.

The absence of residue in the anhydrite [1] points to the view that this substance originated in a manner distinct from the rest of the material deposited from the sea-water.

At certain periods, it seems, a deposit of siliceous material took place. Silica, in the form of compact or friable nodules of chert, occurs in several beds, but chiefly in the Middle bedded rocks on the eastern side of the reef. In many cases, these nodules merge with every gradation into the surrounding dolomite; in others, on removal of the dolomite, they occur as mere angular fragments embedded in recemented calcareous breccias.

The increase of siliceous residue found, in several powdery dolomites (Nos. XXXIII & XXXV), above that in the parent rock whence they were derived, seems to indicate that the change was sometimes accompanied by a slight concentration of silica, tygether with a decomposition of the micaceous, felspathic, and pyritous portions of the residue.

As a rule, the Shell-Limestone, in common with reef-accumulations, is very deficient in residue—sufficient evidence of the absence of silica-secreting organisms. Generally it contains a larger proportion of heavy minerals and a smaller quantity of quartz than most of the bedded rocks. A typical Shell-Limestone residue is that of No. XXXI: it contains occasional large idiomorphic quartz-grains; large flakes of a white mica, showing considerable decomposition; pyrite, with ferruginous material, frequently pseudomorphic after it, resulting from its decomposition; tourmaline and zircon-grains; and occasional small cubical fluorites.

That found in the adjacent powder derived from it contains irregular quartz-grains. Hardly any mica, or pyrite, or ferruginous minerals occur; but tourmalines and zircons are present.

The general scantiness of residue that could be regarded as detitral suggests, either the existence of arid conditions over the adjacent land, or that the drainage into this part of the Permian sea did not affect the clayey and sandy Carboniferous strata presumably exposed round its margins. This is the more noticeable, seeing that plant-remains [2] occur in all divisions of the Magnesian Limestone (except in the reef), where the beds are sufficiently unaltered to allow of their preservation.

Regarding detrital residues, an examination of the residues in relation to the dolomitic nature of the more littoral beds of Yorkshire and Nottinghamshire would be interesting. It is evident in Durham that in the Lower Limestones the residues appreciably increase as we pass westwards and approach the old shore-line.

[1] The conditions of deposition of anhydrite from solution were found by Van 't Hoff to be of a strictly limited nature. They suggest the formation of anhydrite in the upper, concentrated, and heated layers of the sea in seasons of exceptional warmth and desiccation.

[2] These are presumably drifted, although the twigs and fruit of *Ullmannia*, so plentiful in some beds, might be wind-borne.

VII. Summary of the General Conditions of Deposition.

The Marl Slate and Yellow Sands have been so thoroughly described by Prof. G. A. Lebour[1] and others, that there is little for me to add, except a few words about the Marl Slate: it underlies the whole Magnesian Limestone area of Durham. It is from 3 to 8 feet thick, and is variable in composition. It represents a widespread area of tranquil deposition of very thinly-laminated dolomitic and calcareous marl, into which dried, distorted, and partly-decomposed fishes with occasional amphibians and reptiles, plant-remains, coprolitic matter, and shells were periodically drifted, probably from estuarine areas in process of desiccation near land. I do not think that it is itself a lagoon-deposit, since neither sun-cracks, ripple-marks, nor false-bedding have been detected in it. Its equivalent, the German Kupferschiefer, is regarded as a deep-water deposit in the relative sense of the term.

The calcareous beds with a brachiopod fauna, which occur near the base of the Lower Limestones in the south-western Durham area, are due to conditions of deposition during which the process of dolomitic precipitation or of dolomitization was temporarily arrested. The calcareous bed at Thickley Quarry is a lenticular mass interbedded with the dolomite. Examination of partly-decalcified surfaces shows that the rock is very largely composed of small shell-fragments, although thin sections reveal very little structure.

The 60 feet of calcareous beds near the base of the Lower Limestone at Raisby Hill are probably of similar origin, but traces of organic structure are less apparent. Similar beds occur near Masham in North Yorkshire. Otherwise, the Lower Limestone in all its divisions shows a highly dolomitic composition. In Blackhall Sinking, all the beds were dolomitic throughout the 250 feet of the Lower Limestone.

Owing to the comparative absence of soluble sulphates, the segregational changes have been slight, compared with those in the overlying beds; and the Lower Limestone retains to a greater degree than any other division of the Magnesian Limestone its original condition of deposition. Oolites only occur in this division near the Tees, where the Durham facies merges into the more littoral facies of Yorkshire, in which area oolites are conspicuously developed in the Lower Limestone.

Increasingly abnormal conditions are at once apparent in the Middle division, with its long meandering line of reef assuming a true knoll-like aspect on its eastern flank, made up of an enormous accumulation of now-dolomitized organisms, and in their progressive extinction, species after species, on ascending in the reef. The reef was probably deposited about 10 or 12 miles away from the land.

The Middle Beds flanking the eastern and western sides of the reef, in which most of the cellular structures occur, have already been described.

[1] 'The Marl-Slate & Yellow Sands of Northumberland & Durham' Trans. N. Eng. Inst. Min. Eng. vol. liii (1902–1905) p. 18.

The Flexible Limestone is confined to the northern area, east of the reef. It represents a largely detrital deposit, recalling in some ways the conditions of the Marl Slate.

The beds in which concretionary botryoidal structures are developed, were probably of a rather more calcareous nature than the higher beds of the Upper Limestones.

The eastward retrogression of the Upper Limestones with respect, probably to the Middle, and certainly to the Lower Beds, deserves notice, because it has some bearing upon the composition and lithology of the beds themselves. In South Durham the westernmost outlier of the Lower Limestone occurs at least 17 miles to the west of the Upper Limestones, which are here thinning rapidly and changing in character. An examination of the Geological Survey maps of Yorkshire and Nottinghamshire, where the Upper Limestones are mapped, shows a similar retrogression. In Durham the upper beds, especially the concretionary division, thicken on passing eastwards from the reef, while the thickening of the Magnesian Limestone as a whole in Nottinghamshire, on retreating both eastwards and northwards from the shore-line, is noticed by several authors.

This retreat of the Upper Limestones is explicable, not by any theory of uplift, but by that of the shrinkage of the limits of the Permian sea, following on increasingly arid conditions with consequent evaporation and failure of the water-supply. The highly-dolomitic nature of the Highest Limestones in Durham points to the latter effect, while the great development of oolites in these beds may indicate the proximity of tidal or surface-movement of the water.

As regards the eastward thickening of the Upper Limestones on retreating from the shore-line, if the Magnesian Limestone be in reality for the greater part a deposit from the waters of the sea, then the greater the volume of overlying water, the greater will be the quantity of material deposited, especially from the very concentrated waters of the Upper Limestones. The consequence will be a thickening of the deposits on reaching deeper water.

Regarding the hidden salt-deposits of South Durham little can be said, except that their Permian age was established by R. Howse,[1] on the discovery of the three characteristic Upper Zechstein fossils, in an intensely dwarfed condition, in a dolomite-band closely associated with the Salt Measures.

Prof. Lebour[2] remarks upon the limited westward extension of the salt-deposits. They represent, in fact, the final phase in the sequence of events traceable throughout the Magnesian Limestone, and are probably a fragment of the western margin of the great German Upper Zechstein salt-field. In the records of borings there is every indication of a perfect upward passage into the Bunter rocks.

[1] Nat. Hist. Trans. North. & Durham, vol. x, pt. 2 (1890).

[2] 'Handbook to the Geology & Natural History of Northumberland & Durham' Brit. Assoc. (Newcastle) 1889, p. 31.

At the final stage, the level of the Permian sea was probably considerably below that of the oceans. The basin thus formed, when the period of desiccation finally gave place to a different set of conditions, would form a convenient receptacle for the thick Bunter deposits, largely of torrential formation under desert conditions. The Bunter deposits, although transgressive, occupy an area closely corresponding to that of the Permian, so that an apparent upward passage, not only of Upper Permian, but of Middle Permian deposits might occur. If the middle deposits of the Permian consisted of material derived from the same source as the overlying Bunter, the break between the two might become very obscure.

The Keuper deposits are, of course, widely transgressive over all.

VIII. Synopsis of the Main Constituents of Durham Magnesian Limestones.

UPPER.

	Number of Analysis.	Condition of Alteration.	Insoluble Residues.	Calcite.	Dolomite.	Anhydrite, or Gypsum, or Sulphur-trioxide.	Iron or Manganese.	Locality.
Salt Measures.								
Hard, grey, gypsiferous	1	...	1·05	0·54	97·27	1·14	0·46	Teeside Boring.
Hartlepool & Roker Beds.								
White, well-bedded, powdery .	2	...	3·31	2·80	92·29	0·15	1·18	Fulwell Cutting.
White, friable, oolitic. Fossils	3	...	0·76	1·25	98·62	0·08	0·45	Hesleden Dene.
White, friable, massive. Fossils	4	...	0·45	1·82	98·60	tr.	0·30	Hesleden Dene.
Massive oolite	5	...	0·05	1·06	98·86	...	0·40	Hartlepool.
Thinly-bedded, small-grained oolite	6	...	0·58	1·10	98·23	...	0·44	Seaham Harbour.
Upper Limestones with *Chondrites*.								
Soft, well-bedded, fetid	7	...	2·61	1·96	93·47	0·31	0·93	South Durham coast-section.
Similar to the above	8	...	3·80	2·81	92·61	0·17	0·77	South Durham coast-section.
Concretionary Series.								
Spherical concretions	9	S.C.	1·23	77·80	21·03	...	0·18	South Durham coast-section.
Platy concretionary limestone.	10	S.C.	3·01	66·60	29·90	...	0·60	South Durham coast-section.
Soft, fetid, well-bedded	11	...	1·80	8·31	87·75	...	0·75	South Durham coast-section.
Spherical concretions	12	S.C.	1·26	80·95	17·30	0·21	0·45	Fulwell Quarries.
Powdery matrix of the above...	13	S.D.	2·65	6·59	89·75	0·23	1·26	Fulwell Quarries.
Small concretionary aggregates	14	S.C.	1·42	75·96	22·39	tr.	0·47	Fulwell Quarries.
Powdery matrix of the above...	15	S.D.	4·11	8·23	87·20	tr.	1·22	Fulwell Quarries.
The 'great marl-bed'	16	...	5·02	13·07	78·42	tr.	2·41	Fulwell Quarries.
Concretionary 'bluestone'	19	S.C.	0·16	96·34	3·13	...	0·19	Byer's Quarry, near Marsden.
Powdery rock associated with the above	17	S.D.	0·27	5·79	93·19	...	0·59 MnO_2 0·61	Byer's Quarry, near Marsden.
Coarse residue in the above ...	18	S.D.	0·25	5·54	93·05	...	2·20	Byer's Quarry, near Marsden.
Flexible Limestones, etc.								
Typical flexible limestone	20	...	6·70	0·71	91·37	0·11	1·48	Marsden.
Thinly-bedded, flaggy rock......	21	...	3·16	6·22	89·68	0·17	0·72	Hesleden Dene.
Hard, flaggy bedded rock	22	...	42·65	3·56	51·92	...	2·35	West Hartlepool.

		Number of Analysis.	Condition of Alteration.	Insoluble Residues.	Calcite.	Dolomite.	Anhydrite, or Gypsum, or Sulphur-trioxide.	Iron or Manganese.	Locality.
MIDDLE	**Upper Shell-Limestones.**								
	Bedded, powdery, fossiliferous.	23	...	0·31	0·05	99·90	tr.	0·25	Hesleden Dene.
	Bedded, slightly segregated ...	24	...	0·27	11·41	87·73	0·71	0·39	
	Bedded rock, associated with 23 & 24	25	...	0·74	1·06	98·71	0·06	0·23	
	Bedded, porous, fossiliferous...	26	...	0·21	1·55	98·66	0·11	0·23	Castle Eden Dene.
	Coarse-grained oolite	27	...	0·57	23·50	75·73	tr.	0·39	Blackhall Rocks.
	Shell-Limestone Conglomerate.	28	...	0·29	0·00	99·91	tr.	0·17	
	Gasteropod reef-bed	29	...	0·22	1·93	97·90	0·09	0·44	Ryhope.
	Hard compact Shell-Limestone	30	...	0·47	3·68	95·12	tr.	0·37	
	Porous friable Shell-Limestone	31	...	0·20	2·83	97·57	0·16	0·28	Easington Colliery.
	Hard irregular segregations ...	32	S.C.	0·08	92·61	7·42	0·29	0·13	
	Powder associated with the above	33	S.D.	1·14	0·46	97·94	tr.	0·69	
	Coarse residue in the above ...	34	S.D.	2·28	41·34	55·68	0·34	1·11	
	Powder associated with 32 ..	35	S.D.	1·92	2·14	95·05	tr.	1·04	
	Coarse residue in the above ...	36	S.D.	0·50	82·25	17·80	tr.	0·34	
	Calcareous Shell-Limestones.								
	Hard, crystalline, fossiliferous.	37	...	0·10	96·27	3·33	tr.	0·78	Tunstall Hill.
	Similar, partly decalcified	38	...	0·19	89·03	3·94	tr.	MnO_2 7·00	
	Hard, white, dense (dolomitic).	39	...	0·24	2·62	96·41	0·33	0·63	
	Dark brown, partly decalcified.	40	...	0·28	84·35	9·00	0·18	MnO_2 6·67	Beacon Hill.
	Lower Shell-Limestones.								
	Crinoid-stems (dolomitic)	41	...	3·65	0·10	95·97	...	0·32	Claxheugh.
	Powdery material in cells	42	S.D.	2·41	2·39	95·35	...	0·65	Ford Quarry, Claxheugh.
	Calcareous matrix of the above.	43	S.C.	2·04	87·31	11·12	...	0·45	
	Very fossiliferous Shell Limestone..............................	44	...	0·45	3·13	96·25	0·14	0·30	Blackhall Colliery Sinking.
	Similar, with different fossils .	45	...	1·71	4·52	94·15	0·14	0·47	
	Shell-substance of a *Productus*	46	...	0·11	3·91	95·88	tr.	0·28	
	Shell-substance of an *Arca* ...	47	...	0·28	0·24	98·68	tr.	0·56	
	Rock filling a *Productus*-shell.	48	...	1·45	3·01	94·57	tr.	0·67	
	Sulphate-bearing Magnesian Limestones.								
	Very hard, compact, with anhydrite	49	...	1·93	0·02	70·44	Anhydrite 27·85	0·75	Cement-Works boring, Hartlepool.
	Dark grey, with gypsum	50	...	2·32	2·30	86·53	Gypsum 7·58	0·83	
	Middle bedded on Eastern side of Reef.								
	Thinly-bedded, soft, porous ...	51	...	2·31	3·40	94·33	...	0·46	Trow Rocks, South Shields.
	Powder in cavities	52	S.D.	2·55	0·22	97·39	...	0·41	
	Calcareous matrix of the above	53	S.C.	2·69	63·43	33·95	...	0·78	
	Thinly-bedded, compact (Lower)	54	...	0·43	2·35	97·19	...	0·83	
	Soft, white, well-bedded	55	...	1·99	0·46	96·91	..	0·38	Coast near Horden Burn.
	Soft, yellow, well-bedded	56	...	3·14	0·58	96·08	...	0·61	
	Calcareous segregations	57	S.C.	2·35	65·50	31·94	...	0·26	
	Middle bedded on Western side of Reef.								
	Yellow, bedded, fossiliferous ...	58	...	0·16	0·21	99·89	tr.	0·12	Castle Eden Dene.
	Yellow, bedded, fossiliferous ...	59	...	0·05	1·65	98·42	0·10	0·41	
	Very friable, oolitic	60	...	0·02	3·80	96·49	0·07	0·57	Haswell.
	Very friable, non-oolitic.........	61	...	0·12	2·07	98·03	0·02	0·36	

LOWER.

	Number of Analysis.	Condition of Alteration.	Insoluble Residues.	Calcite.	Dolomite.	Anhydrite, or Gypsum, or Sulphur-trioxide.	Iron or Manganese.	Locality.
Lower Limestones. Dolomitic.								
Yellow, friable, bedded, powdery	62	...	0·21	1·05	99·17	...	0·42	Blackhall Colliery Sinking.
Nodular portion in the above	63	...	0·18	1·80	98·68	...	0·13	
Yellow, bedded, rather soft	64	...	0·15	1·70	98·09	0·08	0·59	
White, bedded, compact	65	...	0·12	1·50	98·97	0·03	0·22	
Hard, grey, compact, bedded	66	...	1·01	4·52	92·77	0·14	FeO 2·22	
Thinly-bedded, with plant-remains	69	...	4·15	5·19	88·56	0·15	1·93	Thickley Quarry.
Yellow, hard, bedded, porous	71	...	2·00	5·19	92·04	tr.	1·23	Sherburn Hill.
Brown, friable, well-bedded	72	...	0·69	0·93	98·91	...	0·48	Piercebridge.
Soft, friable, oolitic	73	...	0·23	13·39	86·31	...	0·31	High Coniscliffe.
Dark, bedded, compact, with plants	74	...	3·48	4·91	90·92	...	0·63	Middridge.
Lower Limestones. Calcareous.								
Grey, compact, fossiliferous	67	...	0·63	94·17	3·26	0·08	2·66	Thickly Quarry.
Shell of *Productus* in the above	68	...	nil	97·02	2·48	tr.	0·30	
Grey, nodular, compact, fossiliferous	70	...	1·68	95·27	3·20	tr.	0·37	Garmundsway.
Marl Slates.								
Dark, flaggy, hard	75	...	12·48	10·19	70·67	0·46	0·67	Blackhall Colliery Sinking.
Dark, soft, bituminous, with fish-remains	76	...	41·18	1·65	39·12	1·83	0·56	

In the third column S.C. and S.D. indicate the calcareous and powdery dolomitic portions of segregated rocks. When not otherwise stated, the rock has suffered no greater visible alteration than the leaching-out of soluble sulphates, and the more or less complete oxidation of ferrous compounds common to all the Magnesian Limestones that are unprotected by a covering of anhydrite or of Red Beds.

EXPLANATION OF PLATES XXXVI AND XXXVII.

[All the sections, except Pl. XXXVI, fig. 4, have been treated with Lemberg's solution. The staining is not easily distinguishable in the photographs, on account of darkening due to carbonaceous impurities.]

Plate XXXVI.

Fig. 1. Gypsum and dolomite. Warren Cement-Works Boring, Hartlepool. Analysis No. L. The gypsum is of secondary origin through hydration of anhydrite, and the dolomite, otherwise occurring as allotriomorphic aggregates, develops rhombic outlines where projecting into or lying in the gypsum. × 25. (See p. 243.)

2. Shell-Limestone. Claxheugh, near Sunderland. A bryozoonal and crinoidal reef-deposit. The organisms are almost completely dolomitized, and exhibit a cryptocrystalline structure. The circular object is a crinoid ossicle × 5. (See p. 242.)

Fig. 3. Shell-Limestone. Easington Colliery knoll. Analysis XXXI. Bryozonal Reef. The bryozoa are completely dolomitized. In the cells occur aggregates of clearer calcite and dolomite. The matrix is dolomitic with a few calcareous grains, and is highly contaminated by dirt-inclusions. × 11. (See p. 240.)

4. Calcareous Shell-Limestone. Tunstall Hill. Analysis XXXVII. A portion of the reef which has escaped dolomitization, though a few rhombs of dolomite are seen locally. The slide is made up of sections of bryozoa, brachiopoda, etc., in a mosaic of calcite. The darker portions are due to the presence of carbonaceous and manganiferous material. × 4. (See p. 241.)

5. The Great Marl-Bed. Fulwell Quarries. Analysis XVI. Calcite and dolomite-grains, some of the latter developing rhombic outlines. The calcite tends to separate out along lines apparently of strain or weakness. × 7. (See p. 237.)

Plate XXXVII.

Fig. 1. Anhydrite and dolomite from the base of a mass of anhydrite. Warren Cement-Works Boring, Hartlepool. Analysis XLIX. The anhydrite occurs as radiating stellate aggregates, in a hard, compact, dolomitic matrix. × 10. (See p. 243.)

2. Oolite. Sea-coast section near Castle-Eden Dene. The concentrically-arranged material is dolomite, and each grain is filled with an aggregate of brown allotriomorphic fluorite-crystals, probably of secondary origin. × 7.

3. Oolite in the Upper Limestones. Hardwick Dene. Dolomitic oolites with centres formed of calcitic aggregates, lying in a very loosely-compacted dolomitic matrix. The light portions are original spaces. × 14.

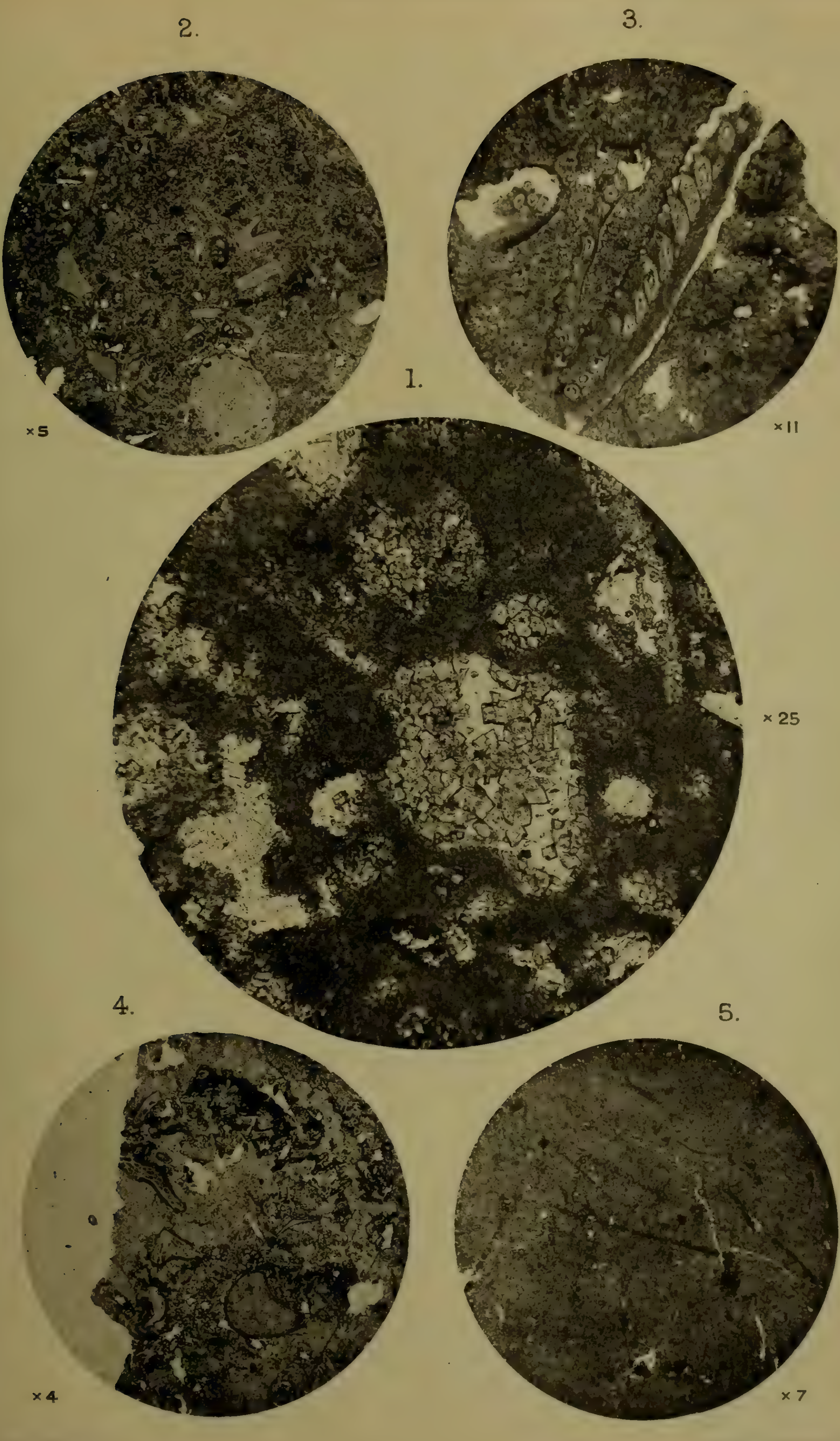
4. A large-grained oolite associated with Upper Shell-Limestone. Analysis XXVII. Blackhall Rocks. The concentrically-arranged material is nearly pure dolomite. Both the nuclei and the matrix are partly dolomitic, and partly calcitic. × 2·5. (See p. 239.)

5. Oolitic bed in the Upper Limestones. Seaham Harbour. The larger spaces are stellate cavities enlarged and obscured in the process of grinding the slice. Analysis VI. A fine-grained dolomitic oolite, the centres dissolved out and the concentric structure almost obliterated through recrystallization of the dolomite in small allotriomorphic grains. × 7. (See p. 235.)

Discussion.

Dr. J. W. Evans expressed his admiration of the Author's careful and detailed work, that formed the foundation of the paper and was in agreement with the conclusions at which he had arrived.

He objected to the use of the word dedolomitization in connexion with the Magnesian Limestone. The term was originally employed for the process by which, in the course of thermal metamorphism, the magnesia was removed from a dolomite and converted either into periclase or into a magnesium silicate, leaving behind pure carbonate of lime. In the case of the Magnesian Limestone there was absolutely no evidence that magnesia had anywhere been abstracted from dolomite. The removal of dolomite in the form of powder was a different process, similar to any other process by which dolomite was eroded without decomposition, and

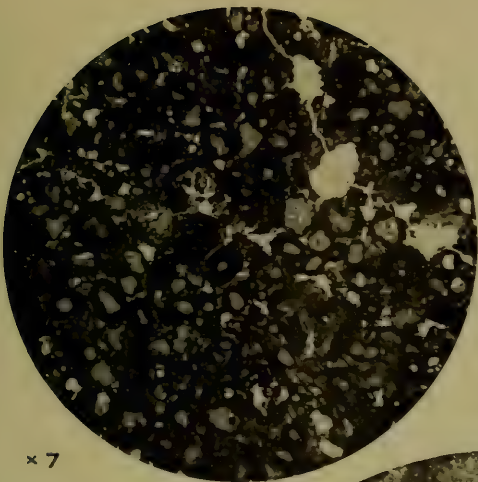


C.T.T., Photomicro.

Bemrose, Collo., Derby

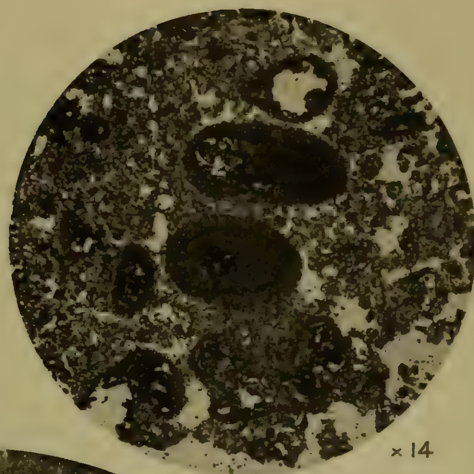
MAGNESIAN LIMESTONES OF DURHAM.

2.



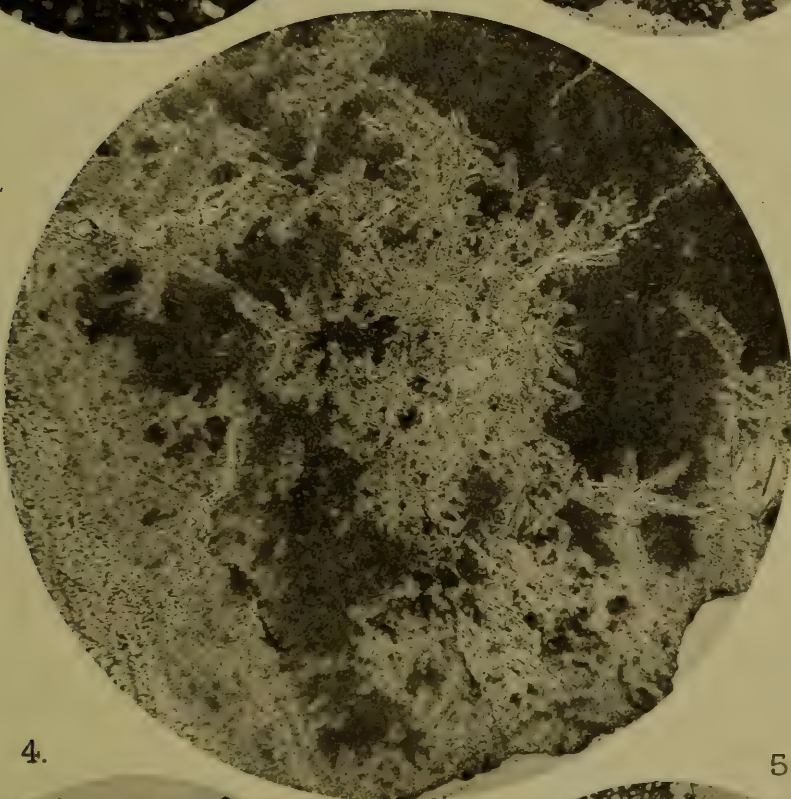
× 7

3.



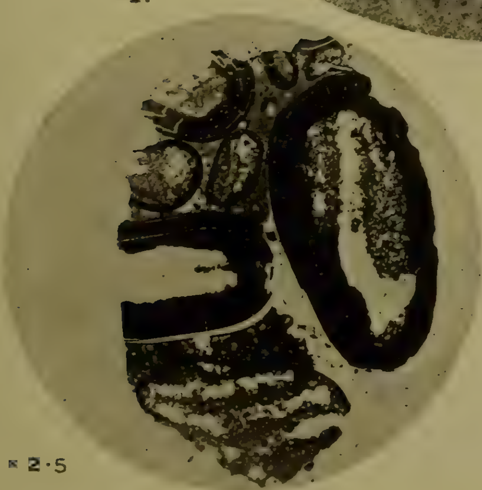
× 14

1.



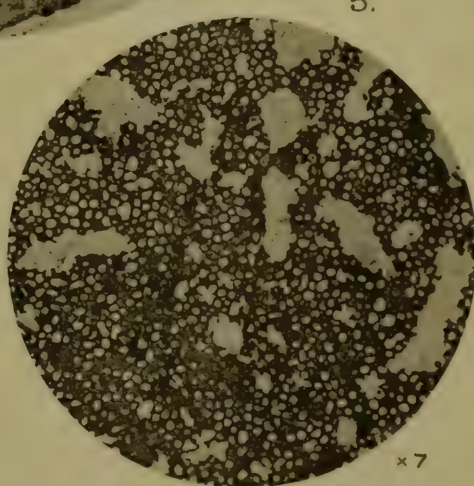
× 10

4.



× 2·5

5.



× 7

C.T.T., Photomicro.

Bemrose, Collo., Derby.

MAGNESIAN LIMESTONES OF DURHAM.

could not properly be defined as dedolomitization. He enquired whether the Author did not think it possible that the oolite-grains had been originally formed of carbonate of lime and subsequently dolomitized by the concentrated sea-water, so that the calcite that formed the core of some grains was original.

He understood from Prof. Kendall that the first suggestion that the cavities in the Magnesian Limestone might be explained by the removal of gypsum in solution was made by Mr. Ernest Guy.[1]

The AUTHOR, in reply, said that the concentric material surrounding the nuclei in the oolites is always practically pure dolomite; in fact, it is among the purest dolomite that occurs in the formation. No trace of originally calcareous oolites was noticed. The nuclei of oolites are sometimes dolomite and sometimes calcite, and this calcite may in some cases be of secondary origin. The evidence is in favour of the dolomite of the oolites having been deposited as such.

Referring to the use of the word dedolomitization, the only term that he could suggest to define the process of washing-out of powdery dolomite was mechanical dedolomitization.

He thought that the former presence of sulphates in the English Magnesian Limestone may have been suspected by many observers, but he could not say by whom the idea was first expressed.

[Sulphate-bearing Magnesian Limestones were found many years ago in sub-Triassic borings in the Tees Valley, and have been more recently recorded in connexion with the sinkings to the concealed coalfield of Yorkshire and Nottinghamshire. The analogy between these gypsiferous dolomites and those at the surface can scarcely have escaped the attention of earlier observers. In Germany the Zechstein is still gypsiferous in many surface-exposures.—*C. T. T., May 26th, 1914.*]

[1] Trans. Leeds Geol. Assoc. pt. xvi (1911) pp. 10–15.

10. *The* Geology *of the* Country *around* Huntly (Aberdeenshire). By William Robert Watt, M.A., B.Sc., F.G.S. (Read January 21st, 1914.)

[Plates XXXVIII–XL.]

Contents.

I. Introduction.

The district of which the geology is here described lies north and west of the Burgh of Huntly in Western Aberdeenshire. The general form of the area and its boundaries can be seen in the accompanying map (Pl. XL), which, with a few exceptions, includes all the localities mentioned in the following pages. Allrick Hill and the Glen Burn lie west of Clashmach Hill; the Hill of Milleath and 'Torryhillock' lie west of Broadland and Drumdelgie; Midplough lies north-east of Rothiemay Station and east of the Deveron.

With the superficial deposits this paper is scarcely concerned. The depression situated east of the high ground of Mungo, Hill of Kinnoir, and Battlehill, occupies the site of a former lake, and the thick deposit of clay hides the junctions along the hollow. Round Huntly many pits have been opened in the river-gravels deposited by the Bogie and the Deveron. Boulder Clay and glacially-striated rock-surfaces occur sparingly.

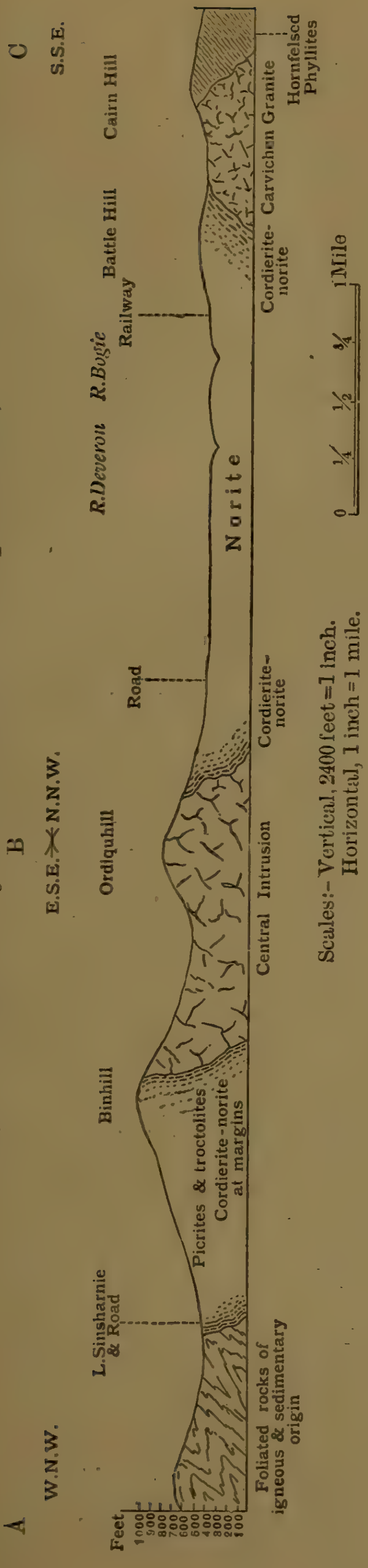


Fig. 1.—*Section along the line ABC in the map (Pl. XL).*

II. The Foliated Series.

Save in the north, where the igneous rocks are continued, the area in question is hemmed in by crystalline rocks, part of the 'Banffshire Series' of Mr. Hinxman[1] —consisting of quartzite, limestone, phyllite, and andalusite-mica-schist. These are well developed on the west of the area, while on the east occur phyllites, grits, and conglomerates.

On the east, the strike of foliation of these rocks varies, from north and south in the north, to north 60° east in the south. The dip of the foliation is vertical, or inclined to the east at a high angle. On the west of the igneous area the strike of the foliation is extremely variable. In the south of the area it is to the west of north; but, following the junction northwards, the strike swings round to the north-and-south line, and finally passes over, becoming near Sinsharnie north 15° east and then north 70° east near Cairnie Church. Farther along the junction, it approximates to the north-east and south-west line. On the west side, the dip of foliation, though nearly vertical where the crystalline and igneous rocks approach one another, decreases to the west and is found to be directed eastwards.

Traversing the crystalline rocks, but foliated with them, are several intrusions represented now by amphibolites and hornblende-rocks, serpentines, pyroxenites, and peridotites. The amphibolites that occur in the west of the area only are well exposed along the Glen Burn in the south. Thence they can be traced through the Hill of Milleath to the Cairnie Burn in the north. Swinging round with the altering

[1] Mem. Geol. Surv. Scot. 1896 Explan. Sheet 75, p. 7.

strike, they are found near Binhall, as also below the farm of Whitehill and to the east of it. Of the rocks of Whitehill, some are found to belong also to the pyroxenites and others to the peridotites. All these rock-types are foliated.

The serpentine-intrusions follow a parallel course, occurring in the south near Allrick Hill, south-west of Clashmach Hill, immediately east of the amphibolites, etc., of the Glen Burn. There is a large serpentine-mass at the Hill of Milleath and at 'Torryhillock.' A third mass is found in the hollow between Mortlach and Whitehill, where the quarries show signs of movement

Fig. 2.—*Sketch-map showing the variation in strike of the foliated rocks of Huntly.* (*See p. 267.*)

[Scale: 2 miles = 1 inch. The heavy black lines indicate the general strike of the rocks.]

in slickensided surfaces. Across the Deveron, a short distance north-east of Rothiemay Station, a fourth mass is exposed at the farm of Midplough. Most of these occurrences show the presence of chrysotile (termed 'asbestos' locally).

South and west of the area, similar bosses of serpentine occur, which, according to Mr. L. W. Hinxman, show signs of crushing, and were therefore grouped by him as of pre-foliation age.[1]

[1] Mem. Geol. Surv. Scot. 1896, Explan. Sheet 75, p. 24; & *ibid.* 1890, Explan. Sheet 76, p. 25.

III. The Non-Foliated Igneous Rocks.

(1) General Characteristics.

The period of great foliation did not, however, terminate the igneous activity of the region, as is proved by the presence of the non-foliated (acid and basic) intrusive rocks which form the subject of this paper. They lie in the concavity formed by the changing strike of the foliation. Other non-foliated igneous rocks include muscovite-granite and pegmatites, lying (outside the area now under consideration) south and west of the Hill of Milleath among foliated rocks. To the action of these, or more probably of the serpentine, may be due the beautiful garnet-chlorite-schists of this area. Near the farm of Bogmoon, also, a non-foliated felspar-porphyry occurs in an area of foliated rocks.

(*a*) The norite group.—In this area there are three non-foliated intrusions and a large number of associated dykes. The largest and earliest of these intrusions—a norite—extends from Fourman Hill to Battlehill. Passing out of sight beneath the alluvium about Huntly, it reappears with slight modifications in Bin Quarry.

This type presents variations, both in texture and in composition. The normal intrusion is a norite with ophitic texture; but in Kinnoir Park it is a gabbro with granitic texture, and on the slopes of Mungo a finely-granular norite. A troctolite is also met with on the western slopes of Mungo.

On the west the norite appears to pass into olivine-gabbros, troctolites, and picrites. No line can be laid down separating these types one from the other, or separating the series, as a whole, from the norite. The western limit of the intrusions is sharply defined by an outcrop of hornfelsed mica-schists near Cairnford Bridge, west of the Deveron. A garnetiferous modification of the magma occurs, apparently *in situ,* near Drumdelgie; but the boundary north of this point is conjectural, until the northern edge of Bin Wood is entered. Here a series of contact-rocks is found lying on the south side of the Cairnie Burn. They can be followed for some distance, but are finally lost in the low-lying ground termed in the Ordnance Survey map Mortlach Loch.

Of the various types in the western portion of the area, the more basic members occur farthest west. Thus the picrite is best developed close to the margin, and occurs at the following localities:—Queels, Cairnford Bridge, quarry east of Broadland, Pyotbush, quarry near Lower Sinsharnie. In the last-named occurrence, the rock is closely related to the troctolite type.[1] An essentially-similar rock forms the main portion of the railway-cutting at Rothiemay, showing the quaquaversal dip of the flat joints.

[1] As used throughout this paper, the term picrite denotes an olivine-pyroxene-rock containing an appreciable amount of bytownite.

East of the picritic type occurs the troctolite, which shows beautiful fluxion-banding. This is well seen in Craighead Quarry—with a similar dip—and at Lower Sinsharnie. Still farther east is found olivine-gabbro, adjoining the norite in both the Dunbennan and the Bin-Hill areas. Fine olivine-gabbros also occur, but between troctolite and picrite, near Cairnford Bridge, and west of Dunbennan Wood, where they form crags.

Having regard to the dip of foliation in the surrounding crystalline rocks, it becomes evident that these basic types of the post-foliation intrusion are grouped along the lower margin of the sill, as if differentiation had taken place under the influence of gravity.

(*b*) The central intrusion.—The second great intrusive mass extends northwards from Broomhillock. Although having in part the composition of a norite, especially at its margin, it is clearly later than and intrusive into the norite already described, as contact-metamorphism occurs in the latter at the junction. The marginal facies of this intrusion shows slight mineral banding, probably due to injection, and is extremely fine-grained, as if it had been intruded when the norite was cooled. As it is composed of hypersthene and plagioclase, its brown colour and the parallel arrangement of its constituents serve to distinguish it from the bluish fine-grained type of the earlier intrusion.

Within this margin, and found mainly in the southern part of the intrusive mass, occurs a coarse non-foliated rock composed chiefly of biotite and felspar. The central and eastern portions of the mass consist of a peculiar rock possessing large garnets, in addition to the felspar and biotite. This rock is referred to as a garnetiferous monzonite, using the term monzonite in the sense in which it is employed by Prof. Brögger.

The distinct types found in this central massif are probably parts of one and the same intrusion. No sign of any contact-metamorphism of one by the other was observed, and it is thought that, if the overlying contact-altered norite on the east were removed, a somewhat symmetrical arrangement about the monzonite type might be observed. What is possibly a further modification of this type is found in Cormalet Hill, where a normal diorite occurs, likewise intrusive into the earlier norite and into the crystalline schists.

(*c*) The Carvichen Granitite.—The third main intrusion occurs in the extreme south-east of the area, and is known as the Carvichen Granitite. In the 'gravel-pit' on Cairnhill it is seen as a decomposed coarse 'sand' beneath the cap of hornfelsed phyllites that form the summit of the hill. The main exposures are found in the quarries near Carvichen, but near Corsiestane an abandoned pit occurs close to garnetiferous grits. Many years ago, a quarry was worked opposite Lintmill, on the right-hand side of the Bogie.

Mention must be made of a highly-foliated rock occurring near Gibstone, and unlike any other hitherto described in this portion of the area. It consists in the main of quartz, augite, biotite, and andesine, but exhibits well-marked mörtel-struktur in section and foliation in the hand-specimen. Near Craigwillie there is a small patch of a dioritic type, not unlike the above, but it is not foliated.

(*d*) The hypabyssal rocks.—As had been expected, many dykes, mainly pegmatitic, occur in the neighbourhood of the Carvichen and Avochie granite-masses. These are well seen in the quarries at Battlehill, and in the railway-cutting near Boghead of Kinnoir. At Ladysmith the veins from the Avochie mass effect considerable metamorphism.

Basic dykes are mainly seen in the cutting at Rothiemay Station, where many are found to be much decomposed. A gabbro-pegmatite occurs near the Mission Kirk of Kinnoir, and a norite-pegmatite cuts the basic rock in the quarry near Broadland.

From the central intrusion, dykes are found traversing and altering the norite in the quarries at Haddoch. A pegmatite there is peculiarly rich in tourmaline, which occurs in crystals of considerable size, usually of triangular cross-section. Fairly often the crystals are terminated by rhombohedral faces.[1]

[1] [The following results of the examination of tourmaline-crystals from a vein in the quarry at Haddoch may be recorded here:—

Simple large crystals.

Prism zone:—

$\left.\begin{array}{l} a\ (11\bar{2}0) \\ m\ (10\bar{1}0) \end{array}\right\}$ In oscillation.

Termination:—

$d\ (50\bar{5}2)$.

$g\ (10\bar{1}2)$.

$z\ (01\bar{1}1)$.

Parallel growths.

As above in each individual.

Hemimorphic crystals.

Prism zone:—

$\left.\begin{array}{l} a\ (11\bar{2}0) \\ m\ (10\bar{1}0) \end{array}\right\}$ In oscillation.

Terminations:—

$\left.\begin{array}{l} r\ (10\bar{1}1) \\ e\ (01\bar{1}2) \end{array}\right\}$ at $+\ c$ termination.

$r\ (10\bar{1}1)$ at $-\ c$ termination.

In all cases m is more strongly developed than a, and the resulting cross-section is triangular.

Tourmaline-pegmatites are not uncommonly associated with the later phases of igneous activity in this region. Other occurrences that may be cited are near Rhynie at Craig Cailleach and west of Drumallachie in Kildrummy.

(2) Petrography.

(*a*) The bytownite-norite.—As was before indicated, this type, covering the largest area, undergoes several modifications of texture and mineral composition. Dark in colour and of medium grain, the typical norite is composed of hypersthene and basic plagioclase, together with monoclinic pyroxene, brown hornblende, biotite, and olivine; while small amounts of magnetite, pyrite, apatite, and zircon are found. Microscopic examination proves the texture to be markedly ophitic.

The hypersthene possesses negative birefringence, strong pleochroism, and many schiller inclusions, while its irregularly-bounded plates are frequently intergrown with a monoclinic pyroxene. The latter may also form a core to a hypersthene shell, or a ring round a hypersthene core, or exist as diallage.

The felspar of the rock was determined from its mean refractive index. The Becke test being used, a liquid of the refractive index of felspar-flakes was obtained by mixing together monobromnaphthalene and dimethylaniline. The refractive index of the liquid was then determined by an Abbé reflectometer for each mixture. In this case the average of several determinations gave $\mu=1{\cdot}567$: this would indicate a felspar the composition of which lay between Ab_2An_3 and Ab_1An_4—that is, a somewhat acid bytownite. The alteration of the felspar is slight, and little schillerization occurs. Twinning on both albite and pericline laws is very common.

Olivine, usually in small rounded grains, is nearly always present in varying amount. Slight alteration to green or brown serpentine may occur, while reaction-rims between the olivine and the felspar are occasionally present. As in the olivines of the gabbro type, the rims are composed of two minerals, here too small for certain identification. The outer pale-green pleochroic mineral is probably actinolite.

Brown hornblende is widespread, though not common. It may crystallize out in parallel growth with the pyroxene, surrounding that mineral like a fringe. Behaving like the pyroxene, it may be ophitic to the plagioclase, or enclose small olivine-grains; while it is often found as a border to small grains of magnetite. Similarly, biotite is of general occurrence, being most abundant in the neighbourhood of Bin Quarry. As it forms here especially along joints, its presence may be due to the later biotite-bearing central intrusion. It is strongly pleochroic in yellow, chocolate-brown, and red-brown.

The only other noritic type in this part of Scotland that is known to me occurs near Rhynie in a small stream—the Broom Stripe—on the north side of the serpentine-mass of Towanreef.

This fine-grained sub-ophitic rock is composed of labradorite and pyroxene, both rhombic and monoclinic, together with some free quartz. The pyroxene may give rise to a secondary green hornblende, which, in the specimens from a neighbouring stream—the Stripe of Clashancape,—is the dominant ferromagnesian mineral. By some, this is considered to represent the original rock now in the condition of serpentine,[1] but it is really an unfoliated dyke-rock cutting the earlier foliated serpentine. It is thus comparable, not only in mineral composition, but also in age, with the unfoliated intrusions in the Huntly area.

(*b*) The gabbro-picrite group.—The olivine-gabbro, the troctolite, and the picrite, which occupy the western portion of the area, are simply lithological variations of the noritic magma. Of the first type, the olivine-gabbro, the essential minerals are felspar, olivine, and pyroxene, and to these brown hornblende, biotite, magnetite, and pyrite are to be added. Of secondary origin are serpentine, anthophyllite, and actinolite.

As before, the felspar is rather basic, but the flakes examined from different gabbros show that the composition has a considerable range. Occasionally the mean refractive index reaches 1·570, but more usually the felspar is a labradorite with a refractive index of 1·560 to 1·564. A slight turbidity may be noticed, and the more basic types show some schillerization.

Of the two varieties of monoclinic pyroxene, diallage predominates in its characteristic form, its brown masses and grains being in marked contrast with the pale greenish ophitic variety. Rarely, the latter predominates. The rhombic pyroxenes are represented by pleochroic hypersthene, which, when present, is often associated with the diallage. Its comparative scarcity contrasts strongly with its abundance in the norite.

From the serpentinized olivine, the usual fissures traverse the felspars, while the resulting serpentine, yellowish or greenish in colour, is (with the residual olivine) strongly charged with magnetite dust. Between olivine and felspar are developed reaction-rims of two or three minerals—anthophyllite and actinolite, with or without brown hornblende. The anthophyllite, distinguished by its straight extinction from the actinolite, and by its cross-cleavage from a rhombic pyroxene, occurs next the olivine. Outside this is sometimes developed a layer of brown hornblende, which, however, may be absent. Outside again, and next the felspar, pale-green pleochroic actinolite occurs. These rims may be of considerable size: one had needles of anthophyllite 5·8 mm. long, followed by needles of actinolite of a length of 5·6 mm.

The brown hornblende is usually charged with magnetite dust; occasionally it forms a shell to the pyroxene, but it is much less common than in the norite series. Biotite is rare; occasionally it forms a ring round magnetite, as do actinolite and brown

[1] Mem. Geol. Surv. Scot. 1890, Explan. Sheet 76, p. 26.

hornblende, in which last cases the magnetite may represent original olivine.

In the neighbourhood of Bin Hill—round the Elfhouse, for example—an olivine-gabbro occurs, which is marked by an increase in the amount of pyroxene and a corresponding diminution in the amount of felspar.

In the troctolite and picrite types, the dominant minerals are felspar and olivine, while the picrites contain in addition pyroxene and amphibole, as well as more abundant olivine. Among the troctolites two modes of weathering can be recognized:—(1) where the green serpentinized olivine occupies depressions among the resistant felspars; and (2) where the felspars have succumbed, and reddish olivines are found in relief. The latter type of weathered rock found near Broomhillock admirably displays the linear arrangement of the constituents.

In addition to the minerals mentioned above, biotite, apatite, magnetite, and pyrite are found. Serpentine (green or brown) is produced in weathering, and, between olivine and felspar, rims of anthophyllite or enstatite and actinolite occur.

In basicity, the felspar varies from rock to rock, being more acid in the more acid rocks. Thus, in the troctolites of Bin Hill and Inchstammack, where there is more felspar than olivine, the mean refractive index of 1·564 would indicate a composition of Ab_2An_3; whereas the banded rock from Craighead Quarry has a felspar whose mean refractive index of 1·570 indicates a bytownite approximating to Ab_1An_4.

In the troctolite forming part of the Rothiemay intrusion the production of rims of fibrous amphibole has been greatly developed, and the remaining felspar is either in part, or completely, altered to prehnite.

In the more basic types, lustre-mottling is well seen, due to the pœcilitic inclusion of the olivines in pyroxene, amphibole, biotite, or felspar. Of the last, fine specimens are found in Sinsharnie Quarry, where the white decomposing felspar meanders among dark grains of serpentine. Though not arranged with any optical constancy, the olivine-grains often show a parallel elongation. Towards the felspars reaction-rims are found. The felspars are in this case basic, with a mean refractive index of 1·570.

The chief pyroxene of the rock is augite, the rock thus being an augite-picrite. The augite becomes altered to a brown opaque mass, which pœcilitically encloses serpentine-grains. At the same time, the felspars, besides being invaded by fibrous amphiboles, are largely altered, with the production of prehnite. With regard to the olivine—hypersthene, brown hornblende, and biotite behave in a similar fashion. The biotite is strongly pleochroic in straw-yellow and reddish-brown, and at the same time possesses a high birefringence. Besides magnetite and pyrite, mention must be made of pleonaste and chromite.

The Rothiemay intrusion is similar to the others, although here the main pyroxene is hypersthene. The felspar is not very abundant,

but is likewise pœcilitic with the olivines. Here, too, are seen scales of a chloritic mineral and laths of actinolite, which are especially well represented in the reaction-borders.

(*c*) *The rocks of the central intrusion.*—The chilled margin of this intrusion betrays its banded nature by the ease with which it splits along certain planes. It is fine-grained and yellowish, showing felspar, rare flakes of biotite, and another ferromagnesian mineral, which microscopic examination proves to be a weakly-pleochroic hypersthene. The mineral banding is now seen to be due to the alignment of the minerals, their directions of greatest length being parallel. The felspars are fresh, and the symmetrical extinction-angles would indicate that they are not more acid than a medium labradorite. Biotite is not abundant, but occurs with the pyroxene and grains of magnetite. A slight variation is afforded by a type near Broomhillock, where the hypersthene is often surrounded by a shell of faintly-pleochroic yellowish-brown hornblende. Here, too, the foliation is less evident.

The second type, much coarser and possessing a granitic texture, shows a yellowish felspar and glistening biotite. In section the mineral content proves to be extremely varied, for associated with the felspar and biotite that form the bulk of the slide are found rhombic and monoclinic pyroxene, hornblende, and quartz; apatite, magnetite, and zircon likewise occur. The plagioclase is now more acid, with a mean refractive index of 1·560: that is, a labradorite of composition approximating to Ab_1An_1. As compared with the normal biotite, the hypersthene is much less common—equalling in amount rather the pale-greenish monoclinic pyroxene. The last is often accompanied by a pale-green hornblende that probably is original. In so basic a rock the presence of free quartz is noteworthy.

Towards the centre of the intrusion, *garnetiferous monzonite* appears—much coarser in texture, and with garnets the average diameter of which reaches 1·3 cm. Quartz, felspar, and biotite are other important constituents; while zircon, apatite, sphene, indicolite, magnetite (often titaniferous), pyrite, and monazite also occur.

Among the felspars are found orthoclase and the two plagioclases, andesine and oligoclase. The plagioclases are occasionally zoned, and in all there is considerable turbidity due to decomposition. Chlorite is an alteration-product of the biotite, and often carries sagenite; it also accompanies the garnet. In this type occur micropegmatitic intergrowths of quartz and orthoclase, both as grains and as fringes to the felspar. At the same time the development of *mörtel-struktur* suggests the operation of dynamic forces.

The monazite occurs in small, biaxial, greenish-yellow, pleochroic grains, having a maximum diameter of 0·18 mm. It was, however, possible to use a spectroscopic eyepiece, and identify the didymium lines.

The second and third of the above-described rock-types have been analysed, and their approximate mineral composition calculated, as follows:—

	I.	II.[1]
SiO_2	53·33	58·22
TiO_2	1·24	·96
Al_2O_3	18·09	19·60
Fe O	1·53	·59
FeO	9·55	5·19
MnO	—	·19
(CoNi)O	—	nt. fd.
BaO	—	·04
CaO	6·02	3·37
MgO	3·92	1·02
K_2O	1·57	5·83
Na_2O	3·72	3·64
Li_2O	—	nt. fd.
H_2O at 105° C.	·12	·14
H_2O above 105° C.	·40	·84
P_2O_5	—	·58
FeS_2	—	nt. fd.
Totals	99·49	100·21

I. Ordiquhill, biotite-felspar rock, east of Ferny Knowe.
II. Ordiquhill, monzonite, west of summit. (E. G. Radley, Anal.)

I.		II.	
Quartz	7·86	Quartz	7·68
Albite	30·92	Orthoclase	27·80
Anorthite	19·46	Albite	30·91
Biotite	15·33	Anorthite	11·68
Diopside	6·96	Biotite	10·82
Hornblende	8·18	Garnet	8·05
Hypersthene	6·10	Apatite	1·24
Magnetite, etc.	4·07	Titaniferous magnetite, etc.	1·60
Total	98·88	Total	99·78

(*d*) The Carvichen Granitite.—The rock composing this intrusion is pale grey, and shows a rude foliation due to the linear arrangement of the constituents, such as the biotite. Although it is used locally for building purposes, the quality of the stone varies greatly—from a hard and durable material to a 'gravel.' The bulk of the rock is seen to consist of quartz, felspar, and biotite, to which a microscopic examination adds garnet, chlorite,

[1] I desire to express my gratitude to the Director of H.M. Geological Survey for permitting these analyses to be carried out in the Survey Laboratories.

muscovite, apatite, and zircon. The foliation is seen in section to be accompanied by slight mörtel-struktur, due to movement during consolidation.

The quartz with its aligned inclusions is perfectly normal, and, having crystallized at a comparatively late period, has been able to corrode the biotite to some extent. Both orthoclastic and plagioclastic felspars are represented, usually a little turbid, owing to the decomposition that has begun. Orthoclase is less abundant than the large crystals of microcline, while the plagioclases are represented by both andesine and oligoclase, the latter in small amount. Biotite is the only abundant ferromagnesian mineral, but presents no unusual features. It alters to a greenish chloritic mica, and is associated sparingly with muscovite.

The rare pink garnets are associated with green mica altering to ordinary chlorite and ripidolitic chlorite. The zircons often possess a greenish-yellow colour strongly suggestive of monazite, but spectroscopic examination did not reveal any didymium lines.

As in so many of the younger microcline-granites of the Highlands, there occur here also micropegmatitic intergrowths of quartz and orthoclase. In this rock there are two types, of which the rarer occurs as grains in the microcline. The other, embracing the bulk of the eutectic, belongs to the fringing type surrounding and projecting into the felspar.[1]

The following analysis of the rock has been made:—

	III.
SiO_2	72·30
TiO_2	0·37
Al_2O_3	12·91
Fe_2O_3	0·59
FeO	2·04
MnO	0·10
(CoNi)O	nt. fd.
BaO	0·03
CaO	1·95
MgO	0·82
K_2O	4·63
Na_2O	3·68
Li_2O	nt. fd.
H_2O at 105° C.	0·03
H_2O above 105° C.	0·55
P_2O_5	0·10
FeS_2	nt. fd.
Total	100·10

III. Carvichen Quarry. (E. G. Radley, Anal.)

(*e*) The hypabyssal rocks.—Basic dykes on the east side of the Deveron are limited to the pegmatite occurring near the Mission Kirk, Kinnoir. In the quarry, this rock is largely

[1] W. Mackie, Trans. Geol. Soc. Edin. vol. ix (1908–10) pp. 274–75.

decomposed to a coarse dark 'gravel' surrounding several hard, more resistant, cores. In section these prove to consist of basic plagioclase, diallage, and hypersthene—the two last-named being often intergrown,—together with a little olivine, brown hornblende, and magnetite. The olivine has become serpentinized, while the felspar is slightly turbid. Very similar to this is the norite-pegmatite traversing the basic intrusion in the quarry below Broadland. Here a pleochroic, schillerized, purplish hypersthene is the predominant ferromagnesian mineral, accompanied by brown hornblende, biotite, and magnetite. The plagioclase is slightly altered, but the light-coloured dyke has largely decomposed.

In the cutting of Rothiemay Station, several dykes are exposed, not as a rule in a very fresh state. The least altered belongs to the norite group, with a pleochroic hypersthene and a sub-ophitic texture. In some cases olivine is developed, and the reaction-rims surrounding this mineral have attained such a size as to destroy the surrounding plagioclase—a destruction hastened by the development of prehnite. The rhombic pyroxene may be nearly colourless and very slightly pleochroic—an enstatite. In places it surrounds the olivine, and the actinolite corona is developed between the enstatite and the felspar. In this case a secondary origin can be ascribed only to the actinolite. Chromite is also present.

A dyke of a bright green colour is found to consist mainly of serpentine and scales of a chloritic mineral. Olivine-cores occur in the serpentine, while, separable from the scales of chlorite by their higher refractive index, occur laths of anthophyllite and actinolite. The chlorite polarizes in pale greys and yellows of the first order, and shows beautiful polysynthetic twinning—a type not uncommon as a secondary mineral in dykes.[1]

In the extreme east of the cutting occurs a fine-grained dyke, composed mainly of labradorite and secondary green hornblende. The margin of this dyke is schistose and much decomposed, but noteworthy for the veins of prehnite that traverse it. In the development of prehnite and occasional schistosity, these dykes recall the features of many of those of the Lizard area.[2]

Acid veins from the intrusions of Carvichen, Avochie, and Ordiquhill are very common, and call for little comment. They consist of quartz, orthoclase, andesine or labradorite, and biotite. As a rule, the norite becomes altered to a rock containing basic plagioclase and green hornblende, as at Haddoch and the cutting near Boghead of Kinnoir.

[1] 'Geology & Structure of the N.W. Highlands of Scotland' Mem. Geol. Surv. 1907, p. 209, &c.; 'Geology of Ben Wyvis, &c.' Mem. Geol. Surv. Scot 1912, Explan. Sheet 93, pp. 84, 117.

[2] Mem. Geol. Surv. 1912, Explan. Sheet 359, p. 116.

IV. Contact-Metamorphism.

(a) The Foliated Rocks.

As a whole, the foliated crystalline rocks of the area have been little affected by the intrusion of these later igneous masses. At Cairnford Bridge, the evidence of contact-metamorphism in the phyllites increases rather to the west—that is, away from these intrusions and towards the foliated intrusions mentioned above (p. 267). The same is true, to some extent, of the exposures along the Cairnie Burn near Gilgatherbush Bridge. Contact-effects due to the later intrusions are, however, met with in Bin Wood south of the Cairnie Burn and the Church, and in Cumrie Plantation. On the south, very similar rocks are found near Ward and on Cairnhill.

Somewhat different rocks, occurring along practically the same strike south-west and north-east of the area, are found on Clashmach Hill and on Fourman Hill. There the andalusite-mica-schist of the district to the south and west is met with: this, having regard to its mode of occurrence, may be the result of antecedent thermal metamorphism. On Clashmach Hill, this rather sandy rock was found to be largely composed of quartz-grains and biotite-flakes, together with some muscovite. The andalusite, as in the case of the similar type described from Buck of Cabrach by Dr. J. J. H. Teall,[1] occurs in large micropœcilitic crystals with inclusions of small biotites and quartzes. Garnet is also present.

In the type occurring on Fourman Hill at Kitty Callin, there are the same dominant minerals, but the place of andalusite may in part be taken by cordierite, which also occcurs in large pœcilitic crystals, enclosing quartz and biotite and showing numerous halos. With the andalusite also occur numerous small staurolites, often twinned.

The phyllite of the district, as seen west of the footbridge at Cairnie Church and near Cairnford Bridge, consists of quartz, biotite, and muscovite often containing sillimanite-needles, with occasionally a little garnet, and felspars both twinned and untwinned. The garnet may be anterior to the folding, as suggested by the behaviour of the biotite-flakes that bend round the resistant grains.

Close to the junction with the later intrusions, rocks are found containing abundant garnet, sillimanite, cordierite, and biotite, the last-named preserving in its arrangement the original foliation. The sillimanite is, with one exception, of the fibrous variety, and is mainly associated, in tufts of highly-refracting needles, with the biotite. Such tufts occur in most of the rocks from Cumrie Plantation and from the neighbourhood of Ward, while they are well developed in the rock forming the top of Cairnhill. The

[1] Mem. Geol. Surv. Scot. 1896, Explan. Sheet 75, p. 36.

exception is the occurrence of the platy variety of sillimanite in the mica-garnet-rock found in the railway-cutting below Boghead of Kinnoir. Finer examples have been described in the aureole of metamorphism of the Ross of Mull granite.[1]

The cordierite of these rocks calls for little remark. It is granular, seldom twinned, and may show an abundance of inclusions with, in most cases, the characteristic halo.

The garnet is the ordinary 'common garnet'—a mixture of the lime, magnesia, and iron molecules, with the last predominating greatly. It is often full of quartz- and felspar-inclusions, and is the typical spongy garnet of a contact-rock. Occasionally, crystal-faces are rather well developed: one example from the slopes above Cobairdy showed the faces $d(110)$ and $n(211)$.

Although the felspars possess considerable range in composition —from oligoclase to labradorite—the majority are andesine and acid labradorite. Orthoclase and quartz are not infrequently intergrown to form 'myrmekite,' and the quartz may show fine hairs—in all probability rutile, as in the quartz of the Netherly diorite.[2] Staurolite is also present in these rocks.

The rocks of Cumrie Plantation are interesting, in that they show signs of the planes of foliation in the numerous stages of absorption that occur among the xenoliths. Where a true hornfels has been formed, these can occasionally be detected by the development of bands of minerals—garnet-rich and cordierite-rich bands alternating.

A different development is observed in the fine-grained rocks of a greenish hue found near Ward. Their colour is due to the presence of a pale-green hornblende, accompanied by cordierite, garnet, quartz, muscovite and biotite, and felspar. A further stage is met with on the slopes of Whitehill, Cobairdy, where the green hornblende and the garnet are better developed, the faces of the garnet being well defined.

In the cutting at Rothiemay Station are to be found two very different types. Here occurs between the two main masses of the intrusion a contact-altered rock, containing both cordierite and hypersthene. The cordierite is uncommon, but not so the hypersthene, which, like the associated pyroxene (diopside), can be traced from a beautifully pleochroic variety to an indefinite aggregate. In part, at least, the presence of this mineral may be due to the impregnation of the crystalline rock by molten material, which, however, has not sufficed to remove all the flakes of biotite.

Very different is the pale rotten material to be found on the north side of the cutting. Its white or pink coloration makes it easily distinguishable from the dark igneous rock. The foliation is well marked, and on fractured surfaces the presence of much biotite can be seen to impart to the rock its colour. In section, both fine-

[1] T. O. Bosworth, Q. J. G. S. vol. lxvi (1910) pp. 376–96.

[2] W. Mackie, Trans. Geol. Soc. Edin. vol. viii (1900–1905) p. 85; and J. S. Flett, 'Geology of Lower Strathspey' Mem. Geol. Surv. Scot. 1902, Explan. Sheet 85, p. 39.

and coarse-grained varieties are seen to consist mainly of minute grains of quartz and small flakes of a contact-biotite. With these are associated bigger grains of quartz and felspar, the biggest showing plagioclase striation and microcline cross-hatching, while a micropegmatite of quartz and orthoclase also occurs. According to Dr. Flett, this is a porphyritic igneous rock, much contact-altered.

(*b*) The Hornblende-Andesine Rock.

It has been previously noted that the most frequent result of the alteration of the norite by the acid dykes and pegmatites was the production of a dioritic type. In the quarry immediately east of Ladysmith, a different rock has been obtained. Here numerous veins penetrate the norite-pegmatites; they are connected with the Avochie Granite intrusion, and are composed of quartz, orthoclase, andesine ($\mu=1{\cdot}554$), and biotite. In width they attain a maximum of 8 or 10 inches; the edges are much richer in biotite than the centre, pointing to the fact that the norite was much colder, at the time of their intrusion. The norite at this place is quite normal, somewhat like that of Battlehill, but slightly coarser.

At some distance from the pegmatites, the norite is seen to contain large black crystals of some mineral, which, as the vein is approached, increase until a border of almost black rock is formed. As seen in section, the first indications of the change are the intergrowth of pyroxene and hornblende—in reality, the conversion of the hypersthene into green hornblende. There is also present much magnetite and biotite, besides bytownite-felspar. So far, the amphibole is confined to single grains occupying approximately the positions of the original hypersthene. As the vein is approached, these separate hornblendes coalesce and now possess the same optical orientation; while the greenish hornblende gives place to a mineral of a rich brown hue. The grains of felspar, somewhat shrunk in size, are enclosed pœcilitically in this crystal. Outside the crystal, hypersthene-grains occur in various stages of transformation.

In the final stages close to the vein, the main portion of the rock is composed of brown hornblende, in large plates pœcilitically enclosing felspar. Biotite is met with sparingly, and acts in the same way. Greenish hornblende passing into brown also occurs, but in a much less compact condition. As compared with the original norite, there is an increase in the amount of ferromagnesian minerals and a decrease in that of felspar. In addition to a diminution in the amount of felspar, there has been a diminution in its basicity. The mean refractive index of the felspar ($\mu=1{\cdot}551$) now indicates andesine, whereas previously it was bytownite. From the felspar and hypersthene, green hornblende was first formed, while magnetite was deposited abundantly. Later, magnetite became less abundant, and the brown variety of hornblende appeared.

(c) Cordierite-Norites and their Allies.

In the Huntly area the rocks of this type can be placed in one of two groups, according to their mode of origin. They are found under different field-conditions, and the same mode of origin cannot be advanced to explain the two occurrences. Here the larger group is composed of rocks, originally norites, that have been altered by the subsequent intrusion of the rocks of Carvichen and Ordiquhill. The resulting cordierite-norites occur, therefore, where the older norite is pierced by these later intrusions; but, at the same time, it is evident that contact-metamorphism alone is not responsible for the whole change—some transfer of material has certainly taken place. The second and smaller group occurs along the western margin of the newer intrusion, at the junction with the crystalline schist. Unfortunately, the boundary is in a cultivated area, and it is an allied type only that seems to occur *in situ*.

In both groups, however, the mineral composition is similar: cordierite, hypersthene, biotite, garnet, and felspar being present. Hypersthene, usually present and necessarily so in the norites proper, is, as a rule, strongly pleochroic, is schillerized, and may be heavily charged with impurities. The hypersthenes of the first group are, on the whole, lighter in colour than those of the second. In the latter there is a tendency to form roughly rectangular grains with a slight linear arrangement. There is a widespread association of the hypersthene with garnet, magnetite, biotite, and pleonaste.

Great variation is noted in the felspars of these rocks. The basic bytownite has now vanished, and the plagioclase is represented by labradorite ($\mu = 1{\cdot}559$) or andesine ($\mu = 1{\cdot}551$); while from the later intrusions orthoclase itself may have passed over. In the formation of this type, the ophitic structure has been broken down, and the felspars are often found as groups of small grains, associated generally with pleonaste.

Biotite, occurring in practically every slice, may be developed to the complete exclusion of hypersthene. For its formation the cordierite-norite is indebted for potash to the intrusive rock. When pyroxene is present, the two minerals are closely associated, and the biotite is often corroded, forming intergrowths with such minerals as quartz, orthoclase, and cordierite.

The cordierite of these rocks contains many zircons surrounded by a characteristic halo. Twinning is common, giving rise to lamellar twins and those of the penetration type (drillingsbildung), showing 'sector-polarization.' In the rocks of the Huntly area, twinning is far more abundant in rocks of igneous origin—the cordierite-hornfelses rarely show twinned cordierites, and never those giving 'sector-polarization.' The restricted occurrence of such twinning was noted by Dr. J. J. H. Teall[1]; but

[1] 'Natural History of Cordierite & its Associates' Proc. Geol. Assoc. vol. xvi (1899–1900) p. 62.

Dr. V. M. Goldschmidt[1] seems to have found it in rocks of sedimentary origin, the chemical composition of which was unaltered by the intruded rock. The cordierite is frequently crowded with inclusions, and shows signs of incipient pinitization.

Two kinds of garnet are to be observed—the normal pink garnet, and, associated with it, a colourless garnet that can be seen to pass into the pink variety. The colourless garnet often bears vermicular markings; and the association—hypersthene, colourless garnet, magnetite, pink garnet, with or without biotite and pleonaste—can be observed wholly or partly developed in many of the rocks where the hypersthene is undergoing change. The bigger garnets are pink, and often contain as inclusions quartz, biotite, felspar, and cordierite.

The green spinel, pleonaste, is present in most slides of the series, as a rule in small amount. Its colour varies considerably from a pale grass-green to a dark olive-green hue. It is a common inclusion in felspar and cordierite, and is grouped round the plates of sillimanite. The last-named mineral is not very common, but it may form either fibrous tufts of needles or fairly large plates similar to those mentioned above. Magnetite, pyrite, and zircon are widespread, while pinite occurs as an alteration-product of the cordierite. Widespread also are minute intergrowths of quartz and acid felspar similar to the myrmekite of the igneous rocks.

Turning to the rocks themselves, we note that the Carvichen intrusion has produced a cordierite-norite at Battlehill Quarry. Veins from the granite traverse the norite here, and their effect is traced in the contact-rock as a whole, which has a specific gravity of 2·82 as against 2·98 for the original norite.

In section, the ophitic texture of the norite is replaced by a granular aggregate of minerals—chiefly hypersthene, felspars, and cordierite. The felspars include orthoclase and labradorite ($\mu =$ 1·559). Both pink and colourless garnets are present, the latter associated with magnetite, hypersthene, and biotite. Biotite is sparingly represented, and the other accessory minerals are pyrite, pleonaste, zircon, and quartz, the last-named usually occurring with the garnet. The presence of quartz and orthoclase is due to the influence of the granite, rather than to any rearrangement of the molecules of the rock.

Round the southern and eastern boundaries of the Ordiquhill intrusion occur a series of cordierite-norites and related rocks. On the eastern slopes of Ordiquhill itself, the garnet-diorite portion of the intrusion is in direct contact with the norite. Here the norite proper is succeeded by a garnetiferous norite with granular structure, wherein the comparatively large garnets are accompanied by quartz and associated with hypersthene. The intruded rock is found to carry, in addition to the minerals of the garnet-monzonite, some strongly pleochroic hypersthene and a little cordierite—pointing to an exchange of material.

[1] 'Die Kontakt-Metamorphose im Kristianiagebiete' Vidensk. Skrift. I. Mat. Naturv. Kl. 1911, No. 11, pp. 358–59.

Intermediate between these two is the contact-norite, where the hypersthene has been largely eliminated and its place taken by biotite. To this is added an increase in the amount of cordierite and in the size of the garnets. Two felspars, at least, occur—orthoclase and andesine ($\mu = 1 \cdot 551$), the former being associated with quartz. Fine intergrowths are formed by the biotite, even with the cordierite. Myrmekitic intergrowths also occur of quartz and acid felspar—the latter having a refractive index lower than that of quartz. The specific gravity of this rock has fallen only to 2·94: as the Carvichen intrusion is much more acid than the Ordiquhill rock, this is only what might have been expected. Naturally, there is great variation in this type, and the chemical analysis and calculated mineral composition may be true of only a very limited type.

In the neighbourhood of Boghead of Gibstone, Broomhillock, and Ordbrae, a much fuller sequence can be made out, thanks to the large number of partly-digested xenoliths. These vary from a norite to a rock composed of biotite, cordierite, garnet, and felspar, passing through, as an intermediate stage, a garnetiferous cordierite-norite.

The early stages are the most interesting, when the rock is mainly composed of hypersthene and cordierite, together with garnet, biotite, and felspar. There is slight pinitization, but the high specific gravity of the rock (3·17) bears witness to the small amount of decomposition. The felspars occur in aggregates of small grains with pleonaste and magnetite, and show symmetric extinction-angles ranging up to 40°—thus indicating a felspar of the composition of bytownite. The biotite is less plentiful than the associated hypersthene, and shows fine intergrowths with the surrounding minerals. Near Broomhillock, a very fine example of a garnetiferous biotite-norite is to be obtained, wherein the colourless garnets are associated with biotite, magnetite, and hypersthene. Towards the biotite, as a rule, the faces of these garnets are well developed—towards the felspars they are usually irregular. This biotite, much more abundant than in the previous case, is beautifully pleochroic in red and yellow. Pleonaste, magnetite, and pyrite occur with the felspars. These last are occasionally labradorite (symmetric extinction-angle = 38°) and usually andesine ($\mu = 1 \cdot 551$). The rock is again very compact and but little altered, having a specific gravity of 3·10.

In the second stage, the hypersthene is being replaced by the biotite, and accordingly hypersthene, biotite, clear garnet, and magnetite are found in close association. The biotite shows numerous intergrowths with felspar, quartz, and cordierite. The felspar is in places not more basic than labradorite, but accompanied by it is an acid felspar forming myrmekitic intergrowths with the quartz. The colourless garnet shows vermicular markings and has magnetite-inclusions, while it passes into the pink variety. Pleonaste occurs as an inclusion in cordierite.

In the following stages the hypersthene has entirely disappeared,

and the dominant ferromagnesian mineral is biotite, forming intergrowths in the less advanced stages. Myrmekitic intergrowths of the felspars and quartz are less common, and slight decomposition may appear. Garnets of both kinds are found often with rectilinear boundaries, and sometimes associated with brownish-green spinel. Of the felspars, orthoclase and labradorite are certainly present, and in some cases the plagioclase has the acidity of oligoclase. These rocks have a specific gravity of 3·04.

In the above-described rocks, sillimanite appeared in the usual fibrous form, but a further stage is exemplified by the appearance of the platy variety. The plates of the mineral are in this case surrounded by a ring of green pleonastes and grains of cordierite. Hypersthene has disappeared, and the biotite shows intergrowths with quartz.

Under slightly different conditions it would seem that a hypersthene is again formed, as in the rock from above Roddentree. Here the minerals now present are garnet, hypersthene, cordierite, and biotite. The hypersthene is spongy, containing numerous inclusions of quartz and felspar. The felspars are basic and acid plagioclase, as well as orthoclase, which is frequently ringed round by a quartz-felspar-micropegmatite, similar to the structure seen in acid plutonic rocks. It is, of course, possible that this represents a type at the beginning of the change from hypersthene to biotite, but the hypersthene of the norite is remarkably free from inclusions such as those mentioned above. In fact, this hypersthene strongly resembles that found in the contact-rock at Rothiemay mentioned previously (p. 280), and a spongy hypersthene is usually one of secondary origin. From its field-relations, it is difficult to see how this rock could represent a contact-altered sediment.

A somewhat different type of development is that seen in the xenolith of the Truttle Stones, where the contact-rock is composed almost entirely of biotite and cordierite. To these may be added labradorite and pink garnet. The halos in the cordierite are numerous and very fine, being occasionally double.

The pegmatite-veins from the Avochie Granite have produced near Ladysmith rocks meriting the name of c o r d i e r i t e - n o r i t e. The hypersthene occurs in large crystals, but has been invariably attacked to form other minerals. Throughout the rock the other minerals occur in small grains. From the hypersthene are developed pleonaste, magnetite, and colourless garnet. The pleonaste and magnetite may occur as inclusions in the hypersthene, in which case they are separated from the pyroxene by a thin band of mineral—usually colourless garnet, but also apparently cordierite. The colourless garnet possesses vermicular markings interlocking with similar projections from the spinel, where the two minerals are in contact. The hypersthene is here broken up, and the colourless rings indicate the medium by which the transference of material was effected. The spinels reach the comparatively large size of 0·53 mm. Cordierite, felspar, and pleonaste make up considerable parts of the rock.

West of the house at Ladysmith, a similar type occurs, where, however, the biotite, scarcely represented in the previous section, has entirely taken the place of the hypersthene. Dark-green spinel-grains occur with felspar and cordierite, and likewise as the core of a normal pink garnet. This would seem to be a further development of the previous type, accompanied by the formation of biotite.

The cordierite-norites of the second type are found in the neighbourhood of Drumdelgie, at Wells Cuternach, and between that and 'The Gray Stane.' They mark the junction between igneous rock and phyllite. In mineral composition they show little difference from the previous group, and here again is observed a gradation from a cordierite-hypersthene type to a garnet-biotite-felspar type, accompanied by a rise in specific gravity from 2·896 to 3·207. To a small extent are developed pleonaste, magnetite, zircon, and quartz.

The hypersthene usually is strongly pleochroic, and of a slightly purplish hue. The cordierite in the rocks where it is abundant is beautifully twinned, showing 'sector-polarization.' Usually, too, it is full of dust-like inclusions, and occasionally is altered to pinite; halos are frequent. Biotite, colourless and pink garnet, and pleonaste present the same features. The felspar is labradorite ($\mu = 1{\cdot}559$) or andesine ($\mu = 1{\cdot}554$), is quite fresh, and always present in some amount. Quartz is sparingly represented, and carries small needles of rutile.

The finest example of cordierite-norite comes from the Wells at Cuternach. In the hand-specimen, the cordierite is so plentiful as to impart to the rock a distinctly greasy lustre. In section the cordierite is seen to be beautifully twinned, possessing also halos and clouds of minute inclusions. It occupies over 50 per cent. of the rock, as is seen from the calculated mineral content. Here the felspar is labradorite of the composition Ab_9An_{11}, approximately. Biotite and hypersthene are the ferromagnesian minerals, the latter predominating over the reddish-brown biotite. The spinel is of a dark brownish-green colour, and seems to form skeleton-crystals. No garnet is present in this rock. This type has been analysed by Mr. Radley (see p. 289).

In no succeeding case is there such a development of cordierite—its commanding position being now taken by labradorite ($\mu = 1{\cdot}559$). Hypersthene and biotite likewise continue, and with them occur magnetite and the two garnets, which merge one into the other as before. Here the colourless garnet shows vermicular markings even towards the felspar, and in the pink garnet the same markings are visible at the edges. Chlorite results from the alteration of the biotite, which possesses its characteristic intergrowths.

Very similar to this type is the rock north of the Gray Stane, differing only in the smaller amount of cordierite. With others at Cuternach this forms a link with those rocks that possess no cordierite. In this final stage, hypersthene has also disappeared

and the garnets are wholly of the pink variety. Though small, these are very numerous, and are set in a matrix of felspar and biotite. The felspar is now not labradorite, but andesine ($\mu = 1 \cdot 544$). With the biotite occurs a titaniferous magnetite, and there seem to be intergrowths of biotite and (?) felspar. Some quartz, bearing rutile-needles, is present.

The association of the minerals cordierite and hypersthene has been previously recorded as occurring both in hornfelses and in rocks of igneous origin. In the case of contact-altered rocks, W. Ramsay[1] described an occurrence where orthoclase and soda-orthoclase intergrown had as inclusions cordierite, hypersthene, biotite, and magnetite, while cordierite and quartz filled the interstices between the felspars. Ramsay came to the conclusion that the rock was the result of contact-alteration, and noted also that the cordierite gave the characteristic 'trillings' (drillingsbildung), a rare phenomenon in a hornfels.

Some seventeen years later a series of such rocks was described from the Christiania district by Dr. V. M. Goldschmidt, who placed them in his Class IV.[2] According to this observer, 20·5 per cent. of the rock is assigned to cordierite, and only 1·5 to hypersthene. By a series of chemical analyses, it is proved that no transference of material has taken place[3] from the igneous rock—unlike, therefore, the rock at the Rothiemay cutting. The cordierite[4] in this case is untwinned, though 'trilling' had been observed in the previous Classes I and II.[5]

In Britain, as an original constituent of plutonic rocks, cordierite has been hitherto found only in the Cornish granites, where it is held to result from the impregnation of the magma by sediments.[6]

Two important papers, dealing with the occurrence of cordierite in basic plutonic rocks, appeared several years ago. The earlier of these, by Prof. A. Lacroix, deals with the intrusion of Le Pallet.[7] Here a gabbro-massif is situated among mica-schists, and an insensible passage can be traced from an olivine-gabbro with labradorite to a cordierite-norite with andesine. In the quarry of Les Prinaux, xenoliths of mica-schist in gabbro occur, and are surrounded by a layer of cordierite-norite that separates them from the gabbro. From this, and from the field-relations, Prof. Lacroix concluded that the cordierite-norite was due to the transformation of the gabbro magma by assimilation of material from the mica-schist. Besides the above-mentioned minerals, it is to be noted that biotite, almandine, and quartz occur.

In Minnesota, a series of similar rocks (to the gabbro type) have

[1] 'Die Älteren, die Nephelinsyenite Umgebenden Gesteine' Fennia, vol. xi, No. 2 (1894) pp. 45–76.

[2] 'Die Kontakt-Metamorphose im Kristianiagebiete' 1911, pp. 160–67.

[3] *Ibid.* p. 23. [4] *Ibid.* pp. 358–59. [5] *Ibid.* pp. 146–154.

[6] 'The Geology of Dartmoor' Mem. Geol. Surv. 1912, Explan. Sheet 338, p. 38; & 'The Geology of the Country around Newton Abbot' Mem. Geol. Surv. 1913, Explan. Sheet 339, p. 67.

[7] 'Le Gabbro du Pallet & ses Modifications' Bull. Carte Géol. France, vol. x (1898–99) pp. 341–96.

been described by Mr. A. N. Winchell,[1] which include a 'muscovadite' or cordierite-biotite-norite. The muscovadite occurs along the northern line of junction of the gabbro mass with the older schists, and is never found away from the junction and contact-zone. The transition from ordinary gabbro to muscovadite, as well as from muscovadite to mica-schist, proceeds by imperceptible degrees. In the rock described, belonging to the gabbro rather than to the schist series, the four common minerals are cordierite, bronzite, biotite, and quartz. Felspar and enstatite are less common, and the accessory minerals are of little importance; staurolite, however, is present.

The felspar is more acid than that of the gabbro, being usually a labradorite (Ab_1An_1) and more rarely andesine (Ab_3An_2). It occurs as small grains, and is not very abundant. Bronzite is more abundant than enstatite, and the reddish-brown biotite is an 'anomite.' The cordierite shows polysynthetic bands and also 'trillings.'

In this case also, Mr. Winchell came to the conclusion that the cordierite-norite was the result of absorption of alumina from external sources—that is, from the surrounding schists.

In tabular form, the mineralogical characteristics of these rocks and the cordierite-norites of Huntly of the second group are:—

Le Pallet.	*Minnesota.*	*Huntly.*
Acid andesine.	Labradorite chiefly.	Labradorite and andesine.
Biotite.	Anomite.	Biotite?
Hypersthene.	Bronzite and enstatite.	Hypersthene.
Halos in cordierite.	Halos wanting.	Halos present.
Almandine.	Almandine wanting.	Garnet usually present.

It is greatly to be regretted that no clear sections exist, to prove in the Huntly occurrence a gradual transition from undoubted igneous rock to undoubted phyllite. On the contrary, the junction takes place in cultivated fields, where for a short distance the plagioclase-garnet-biotite-type alone seems to be *in situ*. To me, however, it appears certain that the rocks of the second type originated from a magma contaminated by the aluminous material of the phyllites, as at Le Pallet and in Minnesota.

In the case of the cordierite-norites of the first type, some absorption of material by the xenoliths and the intruded rocks has certainly taken place. The slices of cordierite-norite from Battlehill show both quartz and orthoclase; orthoclase occurs in the cordierite-norite of Ordiquhill. Such transference of material, however, seems to be slight, and I am inclined to ascribe to the heat of the later intrusion the chief part in bringing about the formation of these cordierite-norites. With differences in temperature and differences in the amount of material transferred, the various types have been formed. The chief chemical changes produced have been an increase in potash and a decrease in the amount of lime.

[1] 'Mineralogical & Petrographical Study of the Gabbroid Rocks of Minnesota' Am. Geol. vol. xxvi (1900) pp. 294 *et seqq.*

Below are tabulated the analyses of a rock from each group, together with a rough calculation of the mineral composition. For comparison, two analyses are added, one taken from Mr. Winchell's paper, the other from that of Prof. Lacroix. While the Huntly rocks are more basic, the chief discrepancy lies in the amounts of magnesia. Potash is also much higher in the Huntly rocks. These discrepancies seem explicable, only on the assumption of the existence of some power of selective absorption in the magma.

ANALYSES OF CORDIERITE-NORITES.

	IV.	V.	VI.	VII.
SiO_2	48·00	49·38	52·84	51·30
TiO_2	0·99	1·24	—	—
Al_2O_3	24·74	22·03	23·62	25·20
Fe_2O_3	0·18	3·11	0·65	2·91
Cr_2O_3	0·21	—	—	—
V_2O_3	trace.	—	—	—
FeO	11·03	11·66	10·00	8·39
MnO	0·24	—	0·43	—
(CoNi)O	nt. fd.	—	—	—
BaO	0·06	—	—	—
CaO	0·99	2·58	3·92	2·50
MgO	9·94	3·84	3·16	4·01
K_2O	1·47	1·84	0·67	0·79
Na_2O	0·84	3·63	2·64	3·82
Li_2O	trace.	—	—	—
H_2O at 105° C.	0·06	0·09	1·87	0·55
H_2O above 105° C.	0·97	0·34		
P_2O_5	0·06	—	—	—
FeS_2	0·59	—	—	—
Totals	100·37	99·74	99·80	99·47
Specific gravities	2·90	2·94	2·81–2·85	2·88

IV. Cordierite-norite, second group, Cuternach. Anal. E. G. Radley.
V. Do. do. first group, Ordiquhill.
VI. Do. do. Minnesota.
VII. Do. do. Quarry of Les Prinaux, Le Pallet.

The mineralogical composition of the Huntly rocks is:—

IV.

Cordierite	53·34
Hypersthene	17·04
Biotite	14·43
Albite	7·34
Anorthite	4·72
Ilmenite, etc.	2·86
Apatite	·12
Pleonaste	·46
Total	100·31

V.

Cordierite	14·40
Hypersthene	3·02
Biotite	13·53
Albite	30·92
Anorthite	12·23
Ilmenite, etc.	4·77
Orthoclase	2·78
Quartz	1·02
Garnet	16·58
Sillimanite	·16
Total	99·41

Frequent reference has been made in the descriptions of the cordierite-norites to the prevalent association of hypersthene, magnetite, and colourless garnet. It may be useful to recall the following facts:—

(1) The colourless garnet bears as inclusions particles of magnetite.

(2) It is usually accompanied by pink garnet, into which it passes insensibly.

(3) It possesses vermicular markings, which are likewise found on the edges of the pink garnet.

(4) The colourless garnet persists so long as there is hypersthene present, and when no hypersthene is present, pink garnet alone occurs.

(5) The colourless garnet, when surrounding hypersthene or magnetite, may or may not be developed towards felspar.

(6) With the formation of pink garnet, there seems to ensue a diminution in the amount of magnetite included in the garnet.

From these facts it appears that the hypersthene is being destroyed to form, by interaction with the anorthite-molecule of the felspar, garnet and a less basic felspar. Magnesia would seem to be lost in the process—the introduction of potash from external sources, however, fixes this as biotite. In the change from hypersthene to ordinary garnet, the colourless variety with inclusions of magnetite constitutes an intermediate stage.

In regard to such garnet-rims, the following previous notices may be of interest. In a gabbro from the Philadelphia district, Miss F. Bascom[1] describes reaction-rims surrounding pyroxene. Usually the pyroxene is hypersthene, but augite or diallage accompany or replace it. The plagioclase is labradorite or labradorite-bytownite. Whether rhombic or monoclinic, the pyroxene is surrounded by a reactionary peripheral rim consisting on the outside of garnet, and within of quartz and hornblende.

In a paper on the origin and growth of garnets, Sir Thomas Holland[2] describes reaction-rims, composed of two layers, between hypersthene and garnets. Next the garnet comes a layer of vermiform pieces of green actinolite, together with felspar showing lamellar twinning. Next the hypersthene is a zone composed of magnetite-granules. In these rocks also, the hypersthene may be accompanied by augite, hornblende, biotite, graphite, and garnet, and

'sometimes it is replaced entirely by garnet in rocks which . . . are beyond question altered forms of the pyroxenic series.' (*Op. cit.* p. 23.)

The centre of the garnets is pink, but towards the margin they show the vermiform cavities with which the above-mentioned actinolites communicate. Along this zone the change proceeds, garnet substance being laid down in the cavities. In this case the garnet grows towards the hypersthene, and not towards the felspar as in the Pennsylvanian case. It is also suggested that there is some relation between the depth of colour in the garnet and the original hypersthene. There is thus a striking similarity

[1] Bull. Geol. Soc. Am. vol. xvi (1905) p. 313.

[2] Rec. Geol. Surv. India, vol. xxix (1896) pp. 20–30.

between the Indian and the Scottish types in regard to the formation of garnet at the expense of hypersthene.

In the rock from Ladysmith, the hypersthene contained inclusions of pleonaste and magnetite. Round both these spinellids, and separating them from the hypersthene, is a zone of colourless mineral (see Pl. XXXVIII, fig. 3). Usually this is isotropic, and has a high refractive index, when it is a colourless garnet; but sometimes its refractive index and birefringence agree with those of the cordierite of the rock.

The colourless garnet showed here also its vermicular markings, which interlocked with greenish outgrowths of the spinel. At this point there would seem to be an intergrowth of spinel and garnet. In the monograph on 'The Charnockite Series,'[1] Sir Thomas Holland records a case where the pleonaste is surrounded by a zone of pale-pink, highly-refracting, isotropic mineral, 'presumably the ordinary magnesia-alumina spinel.' However that may be, it is clear that, in this case also, the hypersthene is being broken up, though in a somewhat different way.

V. Conclusions.

The conclusions arrived at in the foregoing pages may be briefly summarized as follows:—

(1) Two separate series of igneous rocks are to be distinguished, a foliated and a non-foliated series.

(2) The non-foliated series shows signs of movement during injection and consolidation in the prevalence of fluxion-banding and mörtel-struktur.

(3) The non-foliated series contains in itself types of different ages and varied composition.

(4) The later types alter the earlier (non-inflated) norites at their contact with them, with the production of cordierite-norites.

(5) Cordierite-norites are likewise produced in the intrusive rocks by the absorption of material, mainly alumina and magnesia, from the adjacent crystalline rocks—here phyllites more or less hornfelsed.

(6) The cordierite-norite, by the destruction of its cordierite and hypersthene, tends to pass into a rock composed of garnet, labradorite, and biotite.

(7) The destruction of the hypersthene and the formation, with the help of the felspar, of pleonaste, garnet, cordierite, and magnetite, may be noted at various stages.

This research has been carried out at the Imperial College of Science & Technology with the help of a scholarship granted by the Carnegie Trustees for the Universities of Scotland. To Dr. J. S. Flett I am indebted, not only for constant advice, but for the personal labour that he has undertaken in reading the

[1] Mem. Geol. Surv. India, vol. xxviii (1900) p. 168.

manuscript and examining the slides. To Dr. Herbert H. Thomas I offer my best thanks for his help in identifying the rarer minerals. To Dr. C. G. Cullis I desire to record my thanks for the help which I have received in many discussions. At all times I have derived great assistance from Prof. W. W. Watts, for whose kindly interest and criticism I am deeply grateful.

EXPLANATION OF PLATES XXXVIII–XL.

PLATE XXXVIII.

Fig. 1. Contact-rock, first group, west of Ordbrae Crofts, magnified 30 diameters. The crystal showing cleavages in the centre of the field is a plate of sillimanite. With it occur cordierite-grains, and it is surrounded by grains of cordierite and pleonaste with some felspar. Biotite and garnet are likewise present. (See p. 285.)

2. Olivine-gabbro, Cairnford Bridge, magnified 30 diameters, nicols crossed. Olivine-crystals in the position of extinction are fringed with fibrous amphibole, actinolite away from, and anthophyllite near, the olivine. At the centre of the lower portion of the photograph is a plate of brown hornblende, which is found on the left as a third zone round the olivine. Twinned plagioclase and pyrite are also present. (See p. 273.)

3. Cordierite-norite, Ladysmith, magnified 30 diameters. Here three plates of hypersthene are seen to contain inclusions of pleonaste and magnetite, with also pyrite and cordierite. Round the pleonaste, the cordierite, and the pyrite, a ring of colourless garnet occurs; while to the small pleonaste above the centre belongs a ring of cordierite. Grains of cordierite and felspar make up the colourless matrix. (See p. 291.)

PLATE XXXIX.

Fig. 1. Cordierite-garnet-biotite rock, Ladysmith, magnified 30 diameters. This, a further stage of the rock shown in Pl. XXXVIII, fig. 3, exhibits pleonaste-grains with a pink mineral—garnet—surrounding them. Biotite is also present, while the ground-mass is composed of basic felspar and cordierite.

2. Hornblende-andesine rock, Ladysmith, magnified 30 diameters. Composed of a plate of brown hornblende, pœcilitically enclosing grains of andesine. (See p. 281.)

3. Cordierite-norite from Ladysmith, magnified 100 diameters, ordinary light. Shows vermicular garnet surrounding pleonaste and grains of felspar. (See p. 291.)

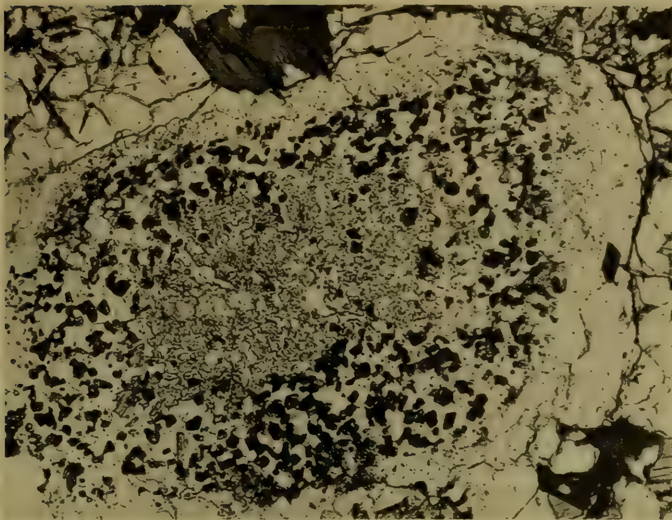
PLATE XL.

Geological map of the neighbourhood of Huntly, on the scale of 1 inch to the mile, or 1 : 63,360.

DISCUSSION.

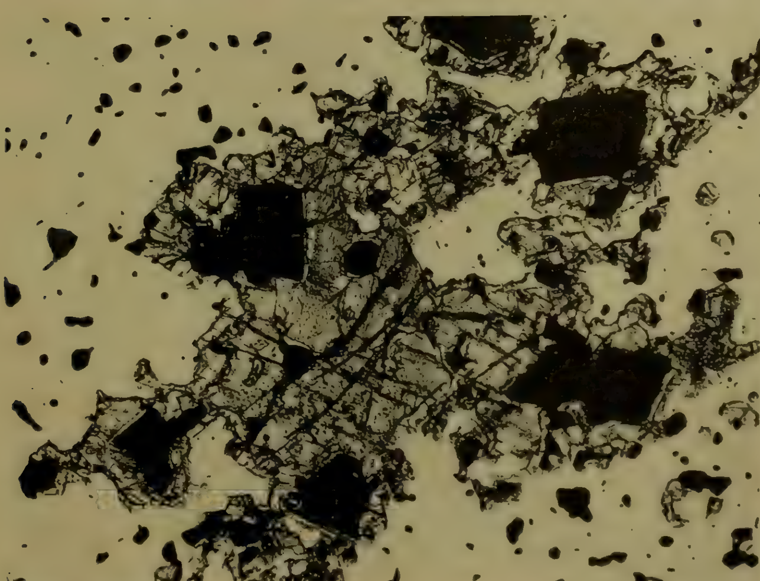
Dr. J. V. Elsden drew attention to the great complexity of the area described by the Author, and to its importance from a petrographical point of view. There appeared to be in the paper evidence bearing upon magmatic differentiation, marginal differentiation, and composite intrusions. With regard to the last-

1. × 30



2. × 30

3. × 30

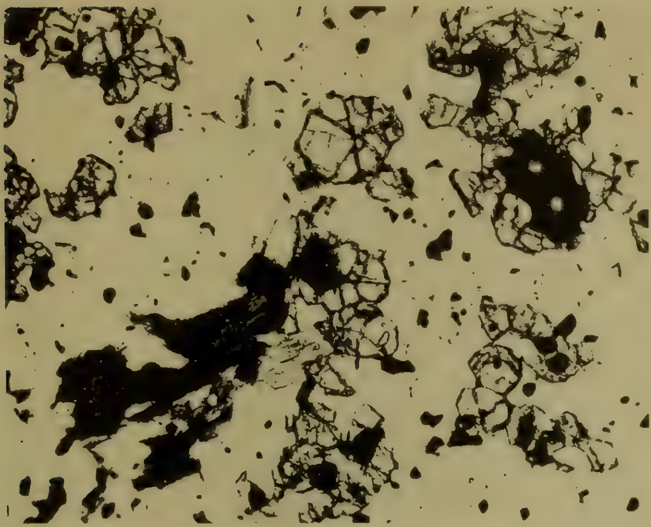


W.R.W., Photomicro.

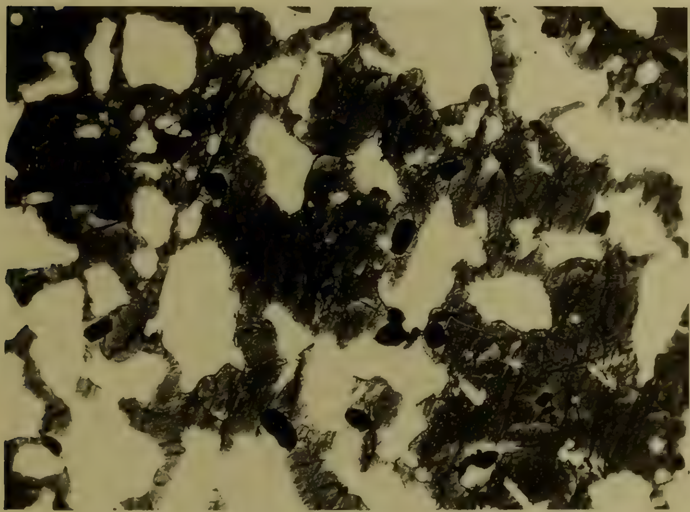
Bemrose, Collo, Derby

OLIVINE-GABBRO; CONTACT-ROCK; AND CORDIERITE-NORITE.

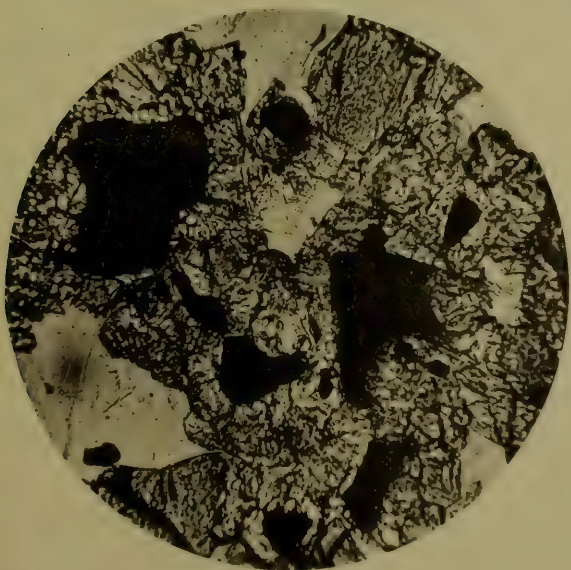
1. × 30



2. × 30



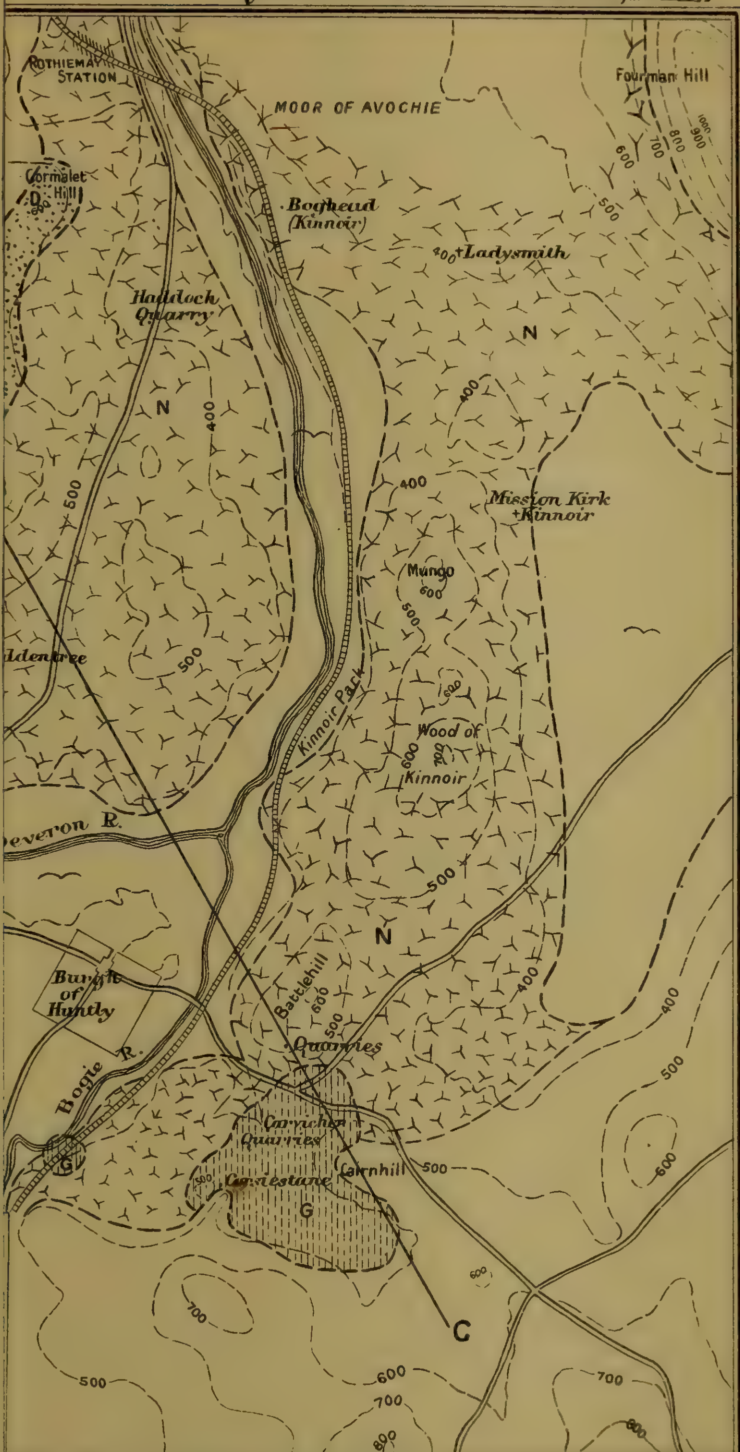
3. × 100



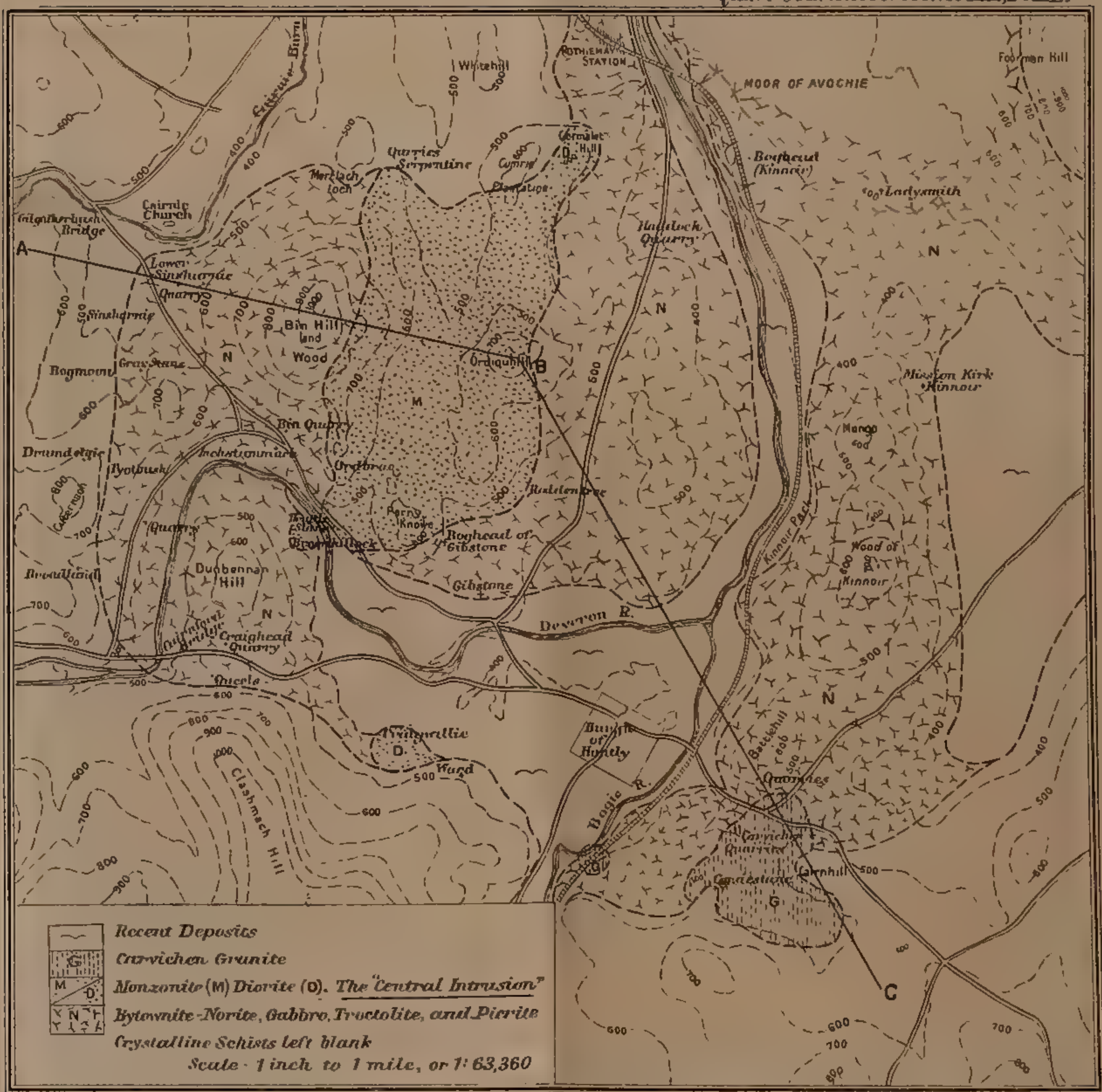
W. R. W., Photomicro.

Bemrose, Collo., Derby.

CORDIERITE-GARNET-BIOTITE ROCK; HORNBLENDE-ANDESINE ROCK; AND CORDIERITE-NORITE.



RY AROUND HUNTLY (ABERDEENSHIRE).



GEOLOGICAL MAP OF THE COUNTRY AROUND HUNTLY (ABERDEENSHIRE).

named, he asked whether the fluxion-bands showed any signs of a mixed magma. The association of minerals described by the Author in the cordierite-rocks was interesting, and the occurrence of sillimanite and spinel was to be expected; but the speaker had heard no mention of corundum, which was often one of the 'faithful companions.' He would be interested to know whether corundum had been observed in these rocks.

Dr. J. W. Evans thought it remarkable that a mineral containing so much silica in proportion to the magnesia and iron-oxide as cordierite did, should occur as a result of the contact-relations of two norites. He was glad that the Author had referred to the case described by Sir Thomas Holland, where garnet appeared to be formed by the alteration of hypersthene. In the Indian rock the colour of the garnet was so remarkably similar to that of the pink vibrations of the hypersthene, that one was irresistibly led to the conclusion that they were related. The conversion of the hypersthene into garnet involved a considerable change in chemical composition, which would, however, be somewhat less if the garnet were pyrope.[1] He would like to know whether the chemical composition of the garnet in the case described by the Author had been ascertained.

Lady McRobert stated that she was familiar with the district, and knew the extreme difficulty experienced in tracing the boundaries of the different zones; she therefore wished to compliment the Author heartily on the successful way in which he had carried out the work.

With reference to Dr. Elsden's question, as to whether there was any evidence of fluxion-banding due to the streaking-out of different magmas, the only such example in the district of which she was aware was a very striking alternation of bands of black troctolite and pale allivalite, which of course only differed slightly in mineral composition. She thought that she was correct in stating that no corundum had been found in association with the cordierite and sillimanite.

Prof. W. W. Watts, replying on behalf of the Author, thanked the Fellows present for the kind reception of the paper.

In reply to Dr. Elsden, he stated that the fluxion-banding was due to arrangement of minerals rather than to the streaking-out of differentiated bands. He pointed out the complexity of the rock-relations which the Author had had to unravel, and said that the district was now ready for additional work on the lines which the Author had laid down but was unable, owing to his absence in India, to follow out.

[1] [A qualitative analysis has shown the presence of both iron and lime in great quantity, and a mere trace of magnesia. The garnet cannot, therefore, be pyrope.—*W. R. W., April 23rd, 1914.*]

11. *The* Composition *of* Rockallite. By Henry Stephens Washington, Ph.D., For. Corr. Geol. Soc. (Read March 25th, 1914.)

Introduction.

An igneous rock of quite exceptional chemical and mineral composition and of unusual petrographic interest is the granitic rockallite. This forms, in part, the small islet of Rockall, situated in lat. 57° 36′ N. and long. 13° 42′ W., about 170 miles west of the Hebrides, and about half-way between Ireland and Iceland. The haycock-shaped islet is almost inaccessible, and only three specimens of the rock are known to be in existence. To quote from a letter (dated December 9th, 1913) received from Prof. J. W. Judd, C.B., F.R.S.:

'Although a number of attempts have been made to examine Rockall, yet, so far as I know, only two landings upon it have been effected. Even in these two cases it was only possible for sailors to jump from a boat on to a projecting point of the rock, and to knock off pieces which they threw into the boat. A carefully-equipped expedition made two voyages to the rock in 1896, but on both occasions had to give up all attempts at landing upon it.'

The rock has been described petrographically in great detail by Prof. Judd,[1] who examined all three specimens, in a paper which forms one of the reports of the Irish expedition of 1896. To these reports the reader may be referred for descriptions of the islet and other information.

Prof. Judd's paper contains a chemical analysis of the 'Inskip' specimen, made by Mr. C. J. S. Makins. As this analysis is far from complete, ferrous oxide, titanium oxide, and water not having been determined, and only a 'trace' of potash reported, and as the rock is of so entirely exceptional a character, it was thought that a new and complete chemical analysis was desirable. Through the kind offices of Prof. Judd and the courtesy of the Governors of the Imperial College of Science & Technology, about half of the Inskip specimen (that analysed by Makins) was given to me for examination and analysis. It is not only a duty but a pleasure for me to acknowledge here my deep sense of gratitude to, and appreciation of the great courtesy and liberality of, these gentlemen for the opportunity to study this exceptionally valuable material. I can but feel gratified that the results of my examination not only confirm the observations of Prof. Judd and Mr. Makins, but have also added some new and rather important features of interest to the rock.

The specimen, as received from Prof. Judd, weighed about 17 grams. Two thin sections were cut, and a fragment of about 6 grams (with one thin section) has been deposited in the Petrographic Reference Collection of the United States Geological

[1] Trans. Roy. Irish Acad. vol. xxxi (1897) pp. 48–58. See also Geol. Mag. dec. 4, vol. vi (1899) pp. 163–67.

Survey. For the analysis about 8 grams were available, a few grams being reserved for optical study and contingencies. I would here express my thanks to Dr. F. E. Wright for kindly undertaking the special optical study of the pyroxene.

Petrographical Description.

The texture of the rock is granitic, somewhat porphyritic in the Inskip specimen according to Prof. Judd, although this was not very evident in my small piece, but non-porphyritic in the other two. It is fine-grained (millimetre-grained), and composed of small anhedra of colourless quartz, white felspar, and thick prisms of a greenish-black pyroxene, the three being present in about equal amount. These three minerals are all perfectly fresh, but there are small specks and patches of a powdery, pale yellow-brown, evidently ferruginous, decomposition-product, apparently limonitic. The water yielded by the analysis shows that the amount of this cannot be great. The specific gravity of this specimen is stated by Prof. Judd to vary between 2·92 and 2·94, that of the other two specimens being 2·77 and 2·71 respectively.

In thin section the rock is seen to be composed almost entirely of sodic pyroxene, alkaline felspar, and quartz, the pyroxene having crystallized first, then the felspar, and last the quartz, as noted by Judd. The pyroxene is in subhedral prisms, with no very definite terminations, and only seldom showing prism or pinacoid faces. Some small subhedral crystals are also included in the quartz and felspar. Cleavage is well-marked, and the crystals carry no inclusions.

The pyroxene is of two kinds. A bright grass-green æ g i r i t e is abundant. The extinction-angle (Wright) varies from 3° to 5°, and the rather strong pleochroism is, as determined by Judd: $\mathfrak{a}$ grass-green, $\mathfrak{b}$ pale olive-green, $\mathfrak{c}$ yellow-green, with the absorption $\mathfrak{a} \geqslant \mathfrak{b} > \mathfrak{c}$. The refractive indices, as determined by Wright, are α=about 1·765, $\gamma > 1{\cdot}80 < 1{\cdot}82$. This green ægirite forms usually the inner portions of the larger prismoids and most of the smaller, isolated, euhedral crystals. The other variety of pyroxene is a pale yellowish-brown a c m i t e, with extinction-angles slightly greater than those of the ægirite. Its pleochroism is not so strong; $\mathfrak{a}$ brown, $\mathfrak{b}$ yellow-brown, $\mathfrak{c}$ brownish yellow. Its refractive index is practically the same as that of the ægirite, but possibly a little higher, and, as Dr. Wright says, the difference optically between the two forms is not so pronounced as one might be led to expect from the difference in colour. This brown acmite generally surrounds the green ægirite, the border between the two being rather irregular but fairly sharp. Rarely the ægirite is exterior to the acmite, especially at the ends of prisms, and there are a few small crystals composed entirely of acmite. Cleavage does not seem to be as well developed in the acmite as in the ægirite.

The f e l s p a r occurs, for the greater part, as comparatively large,

equant subhedral individuals, roughly square in outline. They generally show a fine polysynthetic twinning according to the albite law, Carlsbad twins being rare. The extinction-angles are low, and correspond to those of albite. No microperthite is to be seen. Generally these crystals contain toward the centre some dusty material, which high powers resolve into irregular specks of green ægirite. Albite also forms some small thin laths, often in Carlsbad twins.

The quartz forms anhedral grains, and contains many minute liquid inclusions, which carry gas-bubbles, the volume of the gas-bubble being about 12 to 15 per cent. of the volume of the cavity (Wright). The form of these cavities is sometimes negative. There are a few small, apparently micrographic, intergrowths of felspar and quartz. In these are to be seen very minute prismoidal crystals of a colourless, highly-refracting, optically-positive, uniaxial mineral, which must be referred to zircon. The total amount of this in the sections cannot amount to more than about one-tenth of 1 per cent. Extremely rare and minute grains of magnetite are seen in places, and there are a few very small prisms of apatite. I could find none of the rare blue hornblende mentioned by Prof. Judd.

Chemical Composition.

The chemical analysis was made by me with the greatest care, by the methods advocated by Hillebrand and myself. Zirconia and the rare earths were especially looked for, because of the highly-sodic character of the rock, it being known that these elements are prone to association with sodic magmas.[1] The amounts of both which were found fully justify the search. The 'Ce_2O_3' of the analysis (II, p. 297) was chiefly composed of cerous oxide, as was shown by colour-reactions, but possibly yttrium, didymium, or other rare earths are present. Titanium and manganese were determined colorimetrically. Not a trace of chlorine was leached out of the rock by hot water. Nickel was not looked for, owing to the small amount of material.

It is evident that my analysis fully confirms the general features of Makins's analysis. They both show high silica, ferric oxide, and soda, and low alumina, ferrous oxide, magnesia, lime, and potash. The only noteworthy divergences in the determinations—those in silica, alumina, and soda, and possibly iron oxides, may reasonably be ascribed to the piece analysed by Makins containing a little more quartz and a little less albite and pyroxene than mine, a divergence which is perfectly possible when such small fragments only were available. His high manganese oxide is probably in large part alumina, as coprecipitation of this with the manganese, when the usual sodium-acetate method is used, is a frequent cause of high figures for manganese. The very small amounts of potash and

[1] H. S. Washington, Trans. Am. Inst. Min. Eng. vol. xxxix (1909) p. 755.

phosphorus pentoxide obtained by me would almost justify the application of the term 'trace' to them

	I.	II	III	IV.
SiO_2	73·60	69·80	68·70	68·29
Al_2O_3	4·70	5·10	6·85	8·71
Fe_2O_3	13·10	13·23	9·93	11·60
FeO	n. d.	0·78	1·14	trace
MgO	0·11	0·11	0·26	0·40
CaO	0·37	0·72	1·34	0·51
Na_2O	6·96	8·04	7·01	10·63
K_2O	trace	0·22	1·58	0·67
H_2O+	n. d.	0·46	0·50	n. d.
H_2O-	...	0·31	...	...
CO_2	...	none	...	...
TiO_2	...	0·34	0·26	...
ZrO_2	...	1·17	3·71	[incl. in SiO_2.]
P_2O_5	...	0·07	..	...
SO_3	...	none	...	...
Cl	...	none	...	...
S	...	none	...	...
Ce_2O_3	...	0·37	...	...
MnO	0·93	0·12	trace	...
NiO	0·06	n. d.	...	...
BaO	...	none	...	...
Totals	99·83	100·84	101·28	100·81

I. Rockallite, (II) III. (2) 3. 1. 5. Rockall. C. J. S. Makins, analyst. J. W. Judd, Trans. R. Irish Acad. vol. xxxi (1897) p. 54.
II. Rockallite, ″III. 3. 1. 5. Rockall. H. S. Washington, analyst.
III. Ægirite-granite, II′. 3″. 1. 4. Ampasibitika, Madagascar. Pisani, analyst. A. Lacroix, 'Matériaux pour la Minéralogie de Madagascar' pt. 2, 1903, p. 235 (Nouv. Arch. Mus. Hist. Nat. Paris, ser. 4, vol. v).
IV. Ægirite-granite, (II) III. 4. 1. ″5. Capo alla Cuculla (Corsica). J. Deprat, analyst. Bull. Serv. Carte Géol. France, vol. xvii (1906) No. 114, p. 46.

Analysis II is of especial interest, because of some of the minor constituents. The absence of carbon dioxide, sulphur trioxide, and sulphur was to be expected, and they were only looked for in the regular analytical routine. The same applies to the absence of barium, as this element favours potassic rather than sodic rocks.[1] The amounts of titanium oxide and manganese monoxide are decidedly smaller than was expected, and the presence of what amounts to scarcely more than a 'trace' of phosphorus pentoxide is in accord with the rarity of apatite in the sections examined by me.

The two minor constituents that are of most interest are zirconia and ceria, both of which were found to be present in unexpectedly large amounts. In his letter referred to above, Prof. Judd suggests that the former may be due to zircons present in submicroscopic crystals, as no zircons were visible in his sections. In my two sections some very minute zircons were

[1] *Cf.* H. S. Washington, Carnegie Inst. Publ. No. 57 (1906) p. 188; and Trans. Am. Inst. Min. Eng. vol. xxxix (1909) p. 754.

found in the rare micrographic patches, as noted above. But the total amount of these must be very much less than one half of 1 per cent., probably not more than one tenth of 1 per cent. They certainly cannot be present in amount sufficient to account for the more than 1·5 per cent. of zircon which the amount of zirconia would furnish. We must, therefore, conclude that by far the greater part of the zirconia exists in the pyroxenes. This seems the more probable, as many of the sodic pyroxenes, such as lāvenite, hiortdahlite, etc., contain this element as an essential constituent. This point will be adverted to again.

The rare earths cannot be present as monazite or xenotime, as the small amount of phosphorus pentoxide is needed for the apatite known to be present,—a point also mentioned by Prof. Judd,—and there is no escape from the conclusion that the cerium, like nearly all the zirconium, must be present in the pyroxenes. It may be mentioned that the amount of ceria in rockallite is the highest known to me in any rock, among the many thousands of analyses that I have collected and studied, with the single exception of a nepheline-syenite from Almunge (Sweden), which is shortly to be described by Dr. P. Quensel. This rock contains 48·60 per cent. of silica, 8·74 of soda, and 0·59 of ceria, according to an analysis by Dittrich kindly communicated to me by Dr. Quensel.

Mode.

As the thin sections were small and the granularity relatively coarse, measurement of the mode by Rosiwal's method was not undertaken. But, since the mineral composition of the rock is very simple, the mode may be readily ascertained by readjustment of the norms, which are given on a later page. In these calculations orthoclase is reckoned in with albite, the minute amounts of magnetite and apatite are neglected, the ilmenite is assumed to enter ægirite (for reasons which are given later), and the zirconia to enter the pyroxenes. Data, such as would enable us to ascertain the exact relative amounts of the green ægirite and brown acmite, are lacking; but the former is undoubtedly present in greater quantity. The mode of I is taken from Prof. Judd's paper:—

	I.	II.
Quartz	38	30·4
Albite	23	26·4
Ægirite-acmite	39	43·2

It will be seen that these figures confirm the conclusion drawn from the first inspection of the analyses, that my portion of the Inskip specimen contained somewhat less quartz and more albite and pyroxene than that analysed by Makins. It will also be evident, on comparing the modes and norms, that the mode is essentially normative.

Classification.

In the current classifications rockallite is generally considered as a highly sodic variety of the alkali-granites, although nothing is known of the structural geology of the islet, except that the rockallite overlies an apparently bedded or foliated rock of unknown character. In the 4th edition of his 'Mikroskopische Physiographie' Rosenbusch described it under the granites (vol. ii, pt. 1, 1907, p. 79), but is inclined (*ibid.* p. 611) to consider it as a grorudite (ægirine-quartz-tinguaite), belonging to the dyke-rocks, with which also Prof. Judd compares it. This is an apt example of the fallacy of basing the classification of a rock on the particular portion of the lithosphere where it happened to consolidate, rather than only on characters inherent in the rock itself.

According to the Quantitative Classification, the norms of the two analyses figure out as follows:—

	I.	II.
Q	37·80	30·18
Or	......	1·12
Ab	24·10	25·15
Z	......	1·83
Ac	30·95	37·88
Di	1·70	2·64
Hy	5·08	......
Mt	......	0·23
Il	......	0·61
Ap	......	0·17

They both, therefore, fall in the subrang rockallose, with the general symbol III. 3. 1. 5. Makins's specimen however, is transitional towards the dosalane class, and the domalkalic order, with the exact symbol (II) III. (2) 3. 1. 5, and mine more nearly central, having the symbol "III. 3. 1. 5. It is worthy of note, as indicating the highly exceptional character of this rock, that these two analyses of rockallite are the only representatives of the subrang rockallose (III. 3. 1. 5) among about eight thousand analyses now collected by me.

Affinities of Rockallite.

Both Judd and Rosenbusch remark on a similarity with the grorudites of Brögger. They resemble each other in so far as the qualitative mineral composition is concerned, but the grorudites contain less pyroxene and more felspar, especially considerable orthoclase (as shown by their analyses), and Judd finally considered them as quite distinct from his rock. Similar distinctions also hold good for the pantellerites, with which Judd tentatively compares rockallite on the basis of Foerstner's analyses, but which we now know to be incorrect in many particulars.[1] In recent years there has been an extension of our knowledge of highly sodic

[1] *Cf.* H. S. Washington, Journ. Geol., Chicago, vol. xxi (1913) pp. 702, 707, and vol. xxii (1914) p. 19.

petrographic provinces, and two of these furnish analyses of ægirite-granites which resemble rockallite quite closely. That which resembles it most is the ægirite-rich portion of the alkali-granitic mass of Ampasibitika in Madagascar, the analysis of which is given under III in the Table on p. 297. This has been described by Prof. Lacroix, who calls attention to its close analogy with rockallite. Another is an ægirite-granite from Corsica (Analysis IV), in which island Dr. Deprat has discovered a small province of highly sodic rocks. The symbols of these two granites are respectively II″. 3″. 1. 4 and (II) III. 4. 1. ″5, which express very clearly their relations to the two fragments of rockallite.

The Pyroxene.

The most interesting mineral in rockallite is the pyroxene, some optical data of which, as determined by Wright, have been given on a preceding page. The chemical composition of the two pyroxenes as a whole is very readily calculated from the analytical data, and the results obtained by Judd and myself are given below, together with some recent analyses of other ægirites, and one acmite. The earlier analyses may be consulted in the mineralogical text-books of Dana and Hintze.

	V.	VI.	VII.	VIII.	IX.	X.
SiO_2	51·97	50·63	50·45	51·73	51·08	51·35
TiO_2	...	0·77	0·90[1]	0·64	0·66	...
ZrO_2	...	2·67	0·08[1]	...	...	...
Al_2O_3	none	none	1·78[2]	1·91	0·80	1·59
Ce_2O_3	...	0·84	...	...	...	...
Fe_2O_3	33·48	29·92	23·42	31·86	29·30	32·11
FeO	...	1·64	5·26	0·87	2·29	2·59
MnO	2·41	0·28	0·10	0·60	1·11	0·37
NiO	0·20	...	...	...	...	...
MgO	0·37	0·25	1·48	0·14	trace	none
CaO	0·52	1·41	5·92	0·87	2·54	trace
Na_2O	10·97	11·59	9·84	11·43	11·50	11·39
K_2O	none	none	0·24	0·40	...	trace
H_2O	none	none	0·55	0·20	1·04	...
Totals	99·92	100·00	100·02	100·65	100·32	99·40

[1] Determined by H. S. W. [2] Corrected for TiO_2 and ZrO_2

V. Ægirite-acmite, Rockall. Calculated by Judd.
VI. Ægirite-acmite, Rockall. Calculated by Washington.
VII. Ægirite, Magnet Cove (Arkansas). G. Steiger, analyst. Am. Journ. Sci. ser. 4, vol. xiii (1902) p. 36.
VIII. Ægirite, Quincy (Massachusetts). C. H. Warren, analyst. Am. Journ. Sci. ser. 4, vol. xxxi (1911) p. 553.
IX. Ægirite, Brevik (Norway). S. Hillebrand, analyst. Tscherm. Min. Petr. Mitth. vol. xxxii (1913) p. 249.
X. Acmite, Brevik (Norway). C. Dœlter, analyst. Tscherm. Min. Petr. Mitth. vol. i (1878) p. 381.

It will be seen that the two calculated compositions of the Rockall ægirite agree fairly well, apart from the presence of minor constituents and the probably too high manganese oxide of No. V.

The Rockall pyroxene resembles other ægirite-acmites in general features, but is notably lower in ferrous oxide, especially in comparison with the older analyses. It is also markedly lower in lime, except in the case of the Quincy ægirite (VIII). The amount of titanium oxide is comparable with those in the Quincy and Brevik minerals. As the presence of this constituent was strongly suspected also in the Magnet Cove ægirite, Dr. Steiger not having determined it in his analysis, I obtained, through his kindness, a portion of the material analysed by him, in which I determined titanium oxide and zirconia. The results are given in No. VII, the original figure for alumina (2·76) being corrected for their presence.

There are apparently only five analyses in the literature of brown acmite,[1] and while these are of early date, incomplete, and not wholly satisfactory, they all differ consistently from the analyses of ægirite in their much lower proportion of lime. Ægirite and acmite unquestionably are closely related chemically, crystallographically, and optically in many respects; but the marked differences in colour, character, and strength of pleochroism, and apparently also, but to a less extent, in extinction-angle, indicate a constant chemical difference between the two. This matter has been discussed both by Prof. Dœlter and by Prof. Brögger, but without either investigator arriving at any definite conclusion. This may be attributed in part to the difficulty of obtaining pure acmite substance for analysis, as it is commonly intergrown with ægirite; and in part to the faulty character of the analyses which have been made of this mineral.

The presence of ceria and other rare earths and the large amount of zirconia found in the rockallite, which can be present only or for the greater part in the pyroxenes, suggests that herein is to be found the essential difference between ægirite and acmite: that is, that these constituents are characteristic of acmite, but not of ægirite. All the silicates which contain much cerium, as melanocerite, allanite, cerite, mosandrite, and rinkite, are yellow or yellow-brown, with weak pleochroism. Similarly, it is well known that the zirconia-bearing pyroxenes,—rosenbuschite, låvenite, wöhlerite, hiortdahlite—are all yellowish and have generally weak pleochroism. It may, therefore, be considered possible or probable that ceria and zirconia form an essential part, and are characteristic, of the molecule of the brown acmite, while they are wanting, or are present only to a slight extent, in the green ægirite.

This is, as yet, merely a suggested hypothesis, and, in order to decide the question, complete analyses are needed both of brown acmite and green ægirite, especially that associated with the former. The smallness of the amount of zirconia found by me in the Magnet Cove ægirite (which was the only appropriate material available), would seem to favour the view here advanced; but, of course, a single determination is quite inadequate to settle the matter. The chemical study of these minerals is to be undertaken in the near future.

[1] C. Hintze. 'Handbuch der Mineralogie,' vol. ii (1897) p. 1134, nos. i–v.

Discussion.

Prof. W. W. Watts commented on the exhaustive character of Prof. Judd's account of rockallite from the very scanty amount of material at his disposal. The speaker referred to the strange fact that the rocks of so many of the islands off Britain showed characters unrelated to those of any known rocks on the mainland. He cited especially, in this connexion, Ailsa Craig, Lundy, the Wolf Rock, Bear Island, and Rockall.

Dr. J. W. Evans referred to the fact, to which Dr. Harker had drawn attention in his Presidential Address to the Geological Section of the British Association at Portsmouth in 1911, that alkaline rocks were apt to occur on the margin of igneous areas. Those of Kathiawar, for instance, were found in an outlying portion of the basalts of the Deccan Trap: they might be compared with the Rockall intrusive, which was associated with basaltic rocks, found by dredging in the neighbourhood, that might (as Prof. Grenville Cole had suggested) be of the same age as those of the North-East of Ireland and the Inner Hebrides. The earlier accounts of Rockall which attributed to it a larger area, and in one case mentioned another island in the immediate neighbourhood, might be explained on the supposition that a portion of the basaltic platform had once emerged above the surface of the sea, and had since been removed by marine erosion.

Mr. F. P. Mennell said that he was interested in the Author's suggestion concerning the presence of cerium in the acmite. His own experience in Tropical Africa showed that cerium commonly occurred in the granites as the silicate orthite, or allanite; but there was another occurrence, interesting in the present connexion. Near Bulawayo a rock consisting essentially of microcline and augite occurred. The latter mineral was not ægirite or acmite, but was evidently an alkaline variety—as it was pleochroic, and had an extinction-angle smaller than that of most pyroxenes. In some altered varieties of the rock it was changed to epidote, and certain offshoots were practically transformed into felspar-epidote rocks. The epidote contained brown patches of orthite, which must have been formed from substances originally present in the ferromagnesian mineral.

He noticed that the Author did not regard geological occurrence as an important factor in rock-classification. But, after all, this was the real difference between, for instance, granite and rhyolite. Those who worked at igneous rocks in the field would, he thought, be sorry to give up such intelligible principles as occurrence in favour of purely artificial systems like the Quantitative Classification of which Dr. Washington was joint author.

Mr. R. S. Herries thought that the fact that large islands had been placed, in accordance with reports of early navigators, on the Rockall and other banks was probably due to clouds settling upon the banks and causing at a distance the appearance of land. He reminded the Fellows of a landing on the island, effected some few years ago, when a liner from North America ran on to it and was wrecked with loss of life. Had there been any geologists among the survivors, more specimens of the rock might then have been obtained.

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CONTENTS.

[No. 279 of the Quarterly Journal will be published next September.]

[The Editor of the Quarterly Journal is directed to make it known to the Public that the Authors alone are responsible for the facts and opinions contained in their respective Papers.]

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* **[The Society's Apartments will probably be closed this year from the middle of July until the middle of September, while the work of Redecoration is proceeding.]**

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PART 3.

THE

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OF THE

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EDITED BY

THE ASSISTANT-SECRETARY.

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SESSION 1914–1915.

1914.

Wednesday, December 16*

1915.

Wednesday, January .... 6*—20*
„ February (*Anniversary*, Friday, Feb. 19) .... 3*—24*
March .... 10 —24*
April .... 14 —28*
„ May 12*
„ June .... 9 —23*

[*Business will commence at Eight o' Clock precisely.*]

The asterisks denote the dates on which the Council will meet.

12. ACID *and* INTERMEDIATE INTRUSIONS *and* ASSOCIATED ASH-NECKS *in the* NEIGHBOURHOOD *of* MELROSE (ROXBURGHSHIRE). By RACHEL WORKMAN McROBERT, B.Sc. (Communicated by E. B. BAILEY, B.A., F.G.S. Read February 25th, 1914.)

[PLATES XLI–XLIII.]

CONTENTS.

I. INTRODUCTION.

THE igneous rocks under consideration fall within an area about 7 miles square, included in Sheet 25 of the Geological Survey's 1-inch map of Scotland.

It is generally believed that they date from a late period in the history of the 'Plateau Eruptions' of Calciferous Sandstone times, and correspond with the trachytic lavas and intrusions of the Garleton Hill district (East Lothian), and with the similar intrusions in the Campsie and Renfrewshire hills. The only new evidence obtained, bearing upon this suggestion, weakens rather than supports it: a small neck, the Little Hill, including ash and plugged by basalts of two types, has been found within the Eildon complex of felsitic and trachytic rocks, and is almost certainly of subsequent origin. But it should be borne in mind that the admittedly-late felsitic and trachytic intrusions of the Campsie Fells are in certain cases cut by still later basalts.

The restricted area over which acid rocks of this suite extend in the various districts of Scotland in which they occur is partly due to extreme denudation, and partly to the viscous character of their magma. Only in the Garleton Hills are extensive lava-flows preserved. It seems fairly certain to me that Dr. Peach is right in regarding none of the Melrose rocks as lavas, although the evidence does not altogether exclude the possibility of lavas entering into the Eildon complex.

The rocks may be grouped, according to their field-relations, as follows:—

Laccolites and sills.—White Hill; Black Hill; Bemerside; Eildon Hills; Bowden Moor Quarry; Whitelaw Hill.

Dykes mostly trending north-eastwards.—Several are strung through the country between Melrose and Selkirk; two north-west of Earlston.

Necks.—Chiefswood; Little Hill, described here, although in the main basaltic; a small neck with trachyte, in a little gorge between Bowden Moor Quarry and Rhymers Glen; Faldonside Moor; a small neck on the banks of the Tweed, not visited.

II. Relation to the Upper Old Red Sandstone.

The more easterly masses, such as White Hill, Black Hill, and Bemerside, are associated with the main outcrop of the Upper Old Red Sandstone of Roxburghshire. The more westerly, though situated in advance of this outcrop, in a region predominantly composed of Silurian greywackes, have in certain cases sheltered small outlying patches of Old Red Sandstone. Dr. Peach,[1] who mapped the district for the Geological Survey, shows a somewhat extensive outlier of Upper Old Red Sandstone forming the pedestal of the Eildon Hills, and a long strip at the side of the Chiefswood neck. Mr. J. Pringle[2] has described a minute patch at Whitelaw Hill, Fox's Cover, and Oakwood Mill; in each of these cases it is associated with the igneous intrusions, and I have recently found another under the Bowden-Moor Quarry trachyte. There is also a patch of Old Red Sandstone on the south-eastern flank of Cauldshiels Hill. Although it is not particularly well exposed, I have been led to believe that a good deal of it was got out of the quarry when first worked.

The evidence for these various outliers, except that alongside of the Chiefswood neck and the Eildon Hills, is far from easy to find. The presence of the Bowden-Moor Quarry outlier is betrayed by numerous bits of hard quartz-grit, stained deep red, lying beneath the turf on the south-eastern flank of the hill, just above the farmhouse. At Whitelaw Hill a coarse yellow grit is found at the south-east side of the cap of trachyte, and is attributed by Mr. Pringle to the Upper Old Red Sandstone. At Cauldshiels Hill, baked yellow and red sandstone and mudstone occur on the south-east side of the trachyte-dyke, below the old fort.

The main purpose of the present paper is petrographical. On account of their striking position dominating Melrose, and their curiously barren aspect, the Eildon Hills have so far attracted more attention than the other intrusions. As early as the 'forties' of last century, Prof. Forbes gathered a small collection of typical varieties from the Eildons. This material is still preserved in the Hunterian Museum, Glasgow; but no description seems to have been published. Dr. Peach, in the Geological Survey map of the district published in 1879, gives a useful classification of the igneous rocks of the Melrose district under three headings: intrusive basalt, intrusive felstone, and volcanic agglomerate—the last-named in necks of Calciferous Sandstone age. An important petrographical advance was accomplished by Mr. T. Barron[3] in 1896. He examined rocks from the Eildon Hills and the Black Hill, and demonstrated the occurrence of the rare amphibole riebeckite in the Mid Hill of the former group. He believed

[1] In Sheet 25, Geol. Surv. 1-inch map, published in 1879.

[2] 'Notes on Three Small Outliers of Old Red Sandstone in the Neighbourhood of Selkirk' Trans. Edin. Geol. Soc. vol. ix (1909) p. 351.

[3] Geol. Mag. dec. 4, vol. iii (1896) pp. 373–75.

that nepheline occurred somewhat freely in association with the riebeckite; but it seems unlikely that such is the case, for interstitial quartz is present in most instances, and I have failed to detect nepheline in the many specimens examined (both microscopically and by staining). He also drew attention to the felsitic texture characteristic of the Mid Eildon mass, and to the predominance of typical porphyritic trachytes in 'Easter' Eildon (North). He described the Black Hill, and both here and in the North Eildon suggested the original presence of riebeckite. He regarded the two masses as remnants of lava-streams of Old Red Sandstone age; but his own observations on the Black Hill are strong evidence against such an interpretation. Following this description, we find passing references to the igneous rocks of the neighbourhood in the account given by Dr. Peach & Dr. Horne of the Silurian rocks of Southern Scotland. The 'felstones' are now spoken of as trachytes, and the main features of the Chiefswood neck[1]—its probable Carboniferous age and its contents of greywacke and trachyte-blocks—are touched upon briefly. Dr. Harker[2] has more recently figured a specimen from the Mid Eildon as an example of riebeckite-orthophyre.

It was evidently desirable to obtain a more comprehensive knowledge of the petrology of the district, and with this end in view the various exposures have been carefully examined, and a large number of specimens collected and sliced. In the following pages the intrusions are considered in the order in which they are cited on p. 303.

The chief rock-types represented are:—

(1) Quartz-trachytes.
- (*a*) Non-porphyritic: for instance, Bemerside.
- (*b*) Porphyritic, Black Hill.

(2) Sanidine-trachytes.
- (*a*) Non-porphyritic, Cauldshiels Hill, Whitelaw Hill, etc.
- (*b*) Porphyritic,
  - with fresh riebeckite, Mid Eildon.
  - with ægirine-augite and olivine, Mid Eildon.
  - without fresh ferromagnesian mineral, North Eildon.

(3) Felsites, with fresh riebeckite, Eildon West and Mid Hill.

(4) Quartz-porphyry.

(5) Sanidine-porphyry.

(6) Basalt, Little Hill.

(7) Volcanic agglomerate, ash, etc.

III. Laccolites and Sills.

The White Hill is covered with ploughed fields, and bounded on the north-east and south-east by Upper Old Red Sandstone and on the west by Silurian rocks, but actual contacts are not seen.

[1] Mem. Geol. Surv. 'The Silurian Rocks of Britain' 1899, vol. i (Scotland) p. 190.

[2] 'Petrology for Students' 4th ed. (1908) pp. 128 & 129, fig. 33 B.

It is composed of a fine-grained, pink, orthophyric trachyte rich in soda. The phenocrysts are chiefly orthoclase, or twinned albite with a vein of orthoclase, and some soda-orthoclase. The ground-mass is mainly of orthophyric orthoclase embedded in limonite, which replaces the original ferromagnesian mineral, possibly riebeckite.

The Black Hill, with its steep southern slopes of platy screes, is an intrusive sheet of porphyritic quartz-riebeckite-trachyte, this expression being used to denote a porphyritic trachyte which contains a fair proportion of interstitial quartz. This quartz occurs most freely on the upper part of the sheet.

On the south side of the hill the lower contact of the trachyte with Upper Old Red Sandstone containing scales of *Holoptychius* is well seen in a disused quarry. It runs nearly parallel with the bedding of the sandstone, but cuts across it in places. At the back of the hill the Old Red Sandstone overlies the trachyte, thus forming the roof of the sheet. The rock is sometimes beautifully banded parallel to its floor, which dips gently northwards. In the quarry the trachyte is compact and non-porphyritic at its base; but within a foot above the junction it shows scattered phenocrysts of white sanidine, which increase in number towards the more massive centre of the sheet. The rock is characterized by a platy, crinkly fluxion-cleavage. The best-marked joints are parallel to the dip. When struck with a hammer it emits a peculiar sulphurous smell. The mineral constituents are:—

Sanidine, as fresh phenocrysts, and laths showing Carlsbad twinning in the ground-mass.
Quartz, abundant interstitially.
Limonite, filling spaces among the felspars; in one slide are bluish-green pleochroic needles among the secondary limonite, and these have the habit of the Eildon riebeckite.

The structure is trachytic.

There is a lower sheet in the wood above the road.

Bemerside Hill has been cut into by the Tweed so as to form a steep cliff of non-porphyritic quartz-trachyte (see Pl. XLI, fig. 5). The contacts of the trachyte are everywhere much covered with grass, but the appearances rather suggest a dome-shaped massive intrusion. In the quarry near the turn in the road a well-jointed face is exposed, with one set of joints arching roughly parallel to the outline of the hill, which looks as though its present surface approximately corresponds with the original form of the intrusion. The other set of joints are about 15° from the vertical near the edge, and become vertical near the centre. The rock is purplish and compact, with pinkish-white spots and a few scattered felspar-phenocrysts. It weathers yellow, showing a considerable development of white talc (or kaolin) and pyrolusite along the cracks. Under the microscope it is seen to be a mass of trachytic sanidine-needles, with interstitial quartz and much limonite.

The Eildon Hills are probably the denuded remains of a composite laccolite. The North Hill is petrographically distinguishable, as Mr. Barron has pointed out, from the Mid and Wester Hills, and was probably a subsidiary dome. As the laccolite lies far above the plane of local erosion, its entire sedimentary cover and a good part of the igneous core have been removed. At the present time some 300 or 400 feet of the latter remain. There is no representative of the roof except, perhaps, the narrow band of Old Red Sandstone which is exposed in the quarry between Mid and North Hills. Probably only the eastern half of the laccolite is preserved, as is indicated by the outward dip of the rocks in the north-eastern and south-eastern quadrants. The present western boundary and its three feeders represent the central part of the original laccolite; and the small outlier of Bowden-Moor Quarry, with its strip of underlying Old Red Grit, is probably the sole remnant of the western half.

That the igneous rocks are in the form of thick sheets or a laccolite, rather than a plug, is inferred from the general appearance of the mass; but clear exposures, showing that it has a base, are nowhere available. That portions, at least, of the complex are intrusive is clear from the following considerations:—

A narrow strip of igneous rock connects the North and Mid Hills, and it is seen that this strip, in part at least, has dyke-like relations, for the igneous rock cuts steeply through Old Red mudstone exposed at the brink of a small quarry. The chilled edge against the mudstone is remarkable for its spherulitic structure.

The dyke-like offshoots which break the even western boundary of the Mid and Wester Hills must be transgressive in their relations. The middle one, as exposed in a quarry south of some targets, cuts right across the bedding of the vertical Silurian, and then runs along parallel to the bedding.

The only evidence suggesting the presence of lavas is the rather stratiform appearance of the hills. This is most probably due to the intrusion of the mass sheet by sheet.

The steeper slopes of the Mid and Wester Hills are covered by scree, while the North Hill is much overgrown with grass: continuous zoning of the intrusions is, therefore, fraught with considerable difficulty.

The North Hill has a particularly stratiform appearance. The lowest portion consists of porphyritic sanidine-trachyte, with a spongy aggregate of secondary limonite which recalls the habit of riebeckite. This rock is found next to the Old Red Sandstone in many portions of the complex. Above this, pink non-porphyritic sanidine-trachyte with much quartz is sometimes found; it is composed of sanidine-laths, abundant mossy limonite, probably after riebeckite, and a fair proportion of interstitial quartz. Specimens from below the prominent crags on the north-west side of the hill, and from a corresponding point farther east, show quartz-phenocrysts quite clearly. Under the microscope the quartz-phenocrysts exhibit sharp idiomorphic

boundaries, with very few inclusions; felspar-phenocrysts are entirely chalcedonized, and lie in a microcrystalline ground-mass containing much spongy limonite. It is possible that this quartz-porphyry occurs as a sheet running parallel to the contours, but the nature of the exposure is such that it is impossible to speak with certainty. The topmost rock of the hill, usually ending in an abrupt escarpment, is a highly porphyritic sanidine-trachyte with much quartz. It consists of numerous fresh sanidine phenocrysts in a fine red ground-mass: the latter consists of sanidine-laths, interstitial quartz, and limonite.

No unaltered ferromagnesian mineral has been found in the North Hill, but the habit and distribution of the limonite suggests pseudomorphs after riebeckite.

About 100 feet below the base of the laccolite on the west side is a dyke of the same porphyritic trachyte. It seems to turn into a sheet in the Old Red Sandstone, rising slightly eastwards, and to crop out again in this form on the north and east sides of the hill.

The igneous rock exposed on the col between the North and Mid Hills is a porphyritic trachyte like that of the lower part of the North Hill.

In the Mid Hill similar porphyritic trachyte can be recognized in the lower part of the northern scree-covered slopes adjoining the col just mentioned. It may even extend continuously, perhaps as a basement sheet, to the more northerly of the dykes jutting from the margin of the Mid Hill. This dyke, as also its neighbour on the south, consists of sanidine-porphyry. So far as one can judge on the scree-slope, the more southerly porphyritic dyke extends for some little distance vertically into the overlying felsite. There is, at the same time, the suggestion that the porphyritic rock furnishes a bottom layer to the complex, and reaches across the col between the Mid and Wester Hills.

The porphyritic trachyte of these exposures is red and much stained with limonite. It is rough to the touch, and porous. Amygdales are sometimes abundant, and the jointing is platy. Phenocrysts of fresh sanidine are found, but they are more often pseudomorphosed in kaolinite or chalcedony. They lie in a trachytic ground-mass of small fresh sanidine-laths, spongy limonite, and much secondary quartz filling vesicles and pores. The quartz is sometimes idiomorphic, and is accompanied by chalcedony.

Closely similar porphyries, with a microcrystalline and felsitic ground-mass, also occur.

Much the greater part of the Mid and Wester Hills is formed of riebeckite-felsite (see map, Pl. XLII). The featuring of the two hills suggests that this rock occurs in two layers. The upper layer shows magnificent columnar structure, with very perfect hexagonal columns, on the south-western slopes of the Wester Hill.

The felsite (Pl. XLI, fig. 2) is very hard and compact, and

has yielded a profusion of platy screes. In the lower layer the rock is pink, with small dark patches of riebeckite. Under the microscope the riebeckite-growths are minute, and largely altered to limonite. In the upper layers the rock is purplish grey, weathering pale pink or white, with conchoidal fracture. Fresh riebeckite is abundant in nests and irregular aggregates: it is pleochroic from deep blue to lemon-yellow. The ground-mass is felsitic, with much secondary quartz in large plates. The higher parts of the upper layer become coarser, and show microporphyritic sanidine-crystals; a brownish-green biotite also occurs in one slide from the summit of the Wester Hill.

This rock, as indicated later, is the only one containing fresh riebeckite that is found in any of the necks. In these higher horizons there is an increasing proportion of soda, and phenocrysts of soda-orthoclase have been found in the corresponding rocks of the Mid Hill. These rocks closely approach keratophyres.

Two interesting rocks occur towards the top of the Mid Hill. The actual summit consists of orthophyric riebeckite-trachyte, while to the west of this occurs augite-olivine-trachyte. Hand-specimens from the junction can be selected showing the two types intimately mixed.

The orthophyric riebeckite-trachyte (Pl. XLI, fig. 4) is a very hard, compact, brown rock with a contorted fluxion-cleavage, recalling in appearance corrugated iron. Riebeckite is conspicuous in blue mossy aggregates. Under the microscope, large and fairly abundant phenocrysts of anorthoclase lie in an orthophyric ground-mass of sanidine-prisms, embedded in deep-blue pleochroic riebeckite, and a small quantity of interstitial primary quartz. It is this summit-rock which, as already mentioned (p. 305), has been figured by Dr. Harker.

The augite-olivine-trachyte (Pl. XLI, fig. 3) is a very hard, compact, grey-green rock, with good felspar-phenocrysts. It weathers to a buff colour, and has an irregular fracture. Its small, fresh ground-mass felspars impart to it a saccharoidal lustre. The phenocrysts are orthoclase, with probably some anorthoclase, and ægirine-augite in long thin crystals showing transverse sections with (100) and (110) developed almost to the exclusion of (010). The extinction-angle of this ægirine-augite is 5° to 9°. The ground-mass in which the phenocrysts lie consists of trachytic sanidine, with fluidal arrangement, and abundant, fresh, bright-green ægirine-augite microlites. The olivine is represented by occasional yellow or reddish-brown pseudomorphs of characteristic shape.

As the olivine increases, the pyroxene changes from ægirine-augite to grey-green augite with an extinction-angle of 43°, and is confined to the ground-mass, which latter becomes orthophyric. Soda-felspars preponderate: both twinned and untwinned albite occur, the latter with a rim of orthoclase. Zircons of large size occur, both in this and in the riebeckite-trachyte.

This augite-olivine-trachyte closely resembles specimens from Traprain Law and the Bass Rock (East Lothian). It is more

likely that nepheline will be found in this type than in any of the others met with in the Eildon Hills, but as yet neither microscopic examination nor staining has revealed any.

Bowden Moor Quarry.—Near Bowden Moor, half a mile due west of Eildon Wester, is an oval, grass-covered mound, of which almost the whole interior has been quarried away. The quarry yields a fine-grained, pink, compact trachyte, showing scattered small sanidine-phenocrysts, generally decomposed. These lie in a trachytic ground-mass of sanidine-laths, with a certain amount of primary interstitial quartz, sometimes enclosing the laths ophitically. Secondary quartz is abundant in small vesicles. Limonite, in spongy aggregates and large masses, possibly represents original riebeckite. The rock, as a whole, resembles the trachyte of the spur extending westwards from Eildon Wester Hill.

The Whitelaw Hill Sill lies about a mile and a quarter south-west of the above, and is petrologically so similar that it does not require description. It forms the oval cap of the hill, its longest diameter being about 10 yards. It is in contact with Silurian shales and greywackes, except on its south-east side, where a coarse yellow grit is found, which Mr. Pringle attributes to the Upper Old Red Sandstone. The north-western boundary is a black-banded flinty rock with conchoidal fracture, which extends for some distance beyond the present position of the trachyte. It would seem to be a fine-grained shale, intensely indurated by silicification subsequent to the intrusion. The mass appears to be in connexion with a dyke which runs south-eastwards from the hill-top.

IV. Dykes.

The dykes of the district nearly all run in a general north-easterly direction; it is certain that many of them belong to the same suite of intrusions as the laccolites and sills just described, but it is possible that some may date from the Lower Old Red Sandstone period of igneous activity.

The field-evidence bearing upon the point is as follows:—Two trachyte-dykes of rather irregular form cut the Upper Old Red Sandstone north-west of Earlston. Two others are met with in the narrow strip of the same formation bordering the Chiefswood neck, while a quartz-porphyry dyke is found actually within this neck. A large trachyte-dyke forming Cauldshiels Hill, though in the main traversing Silurian strata, cuts across a small outlier of the Upper Old Red Sandstone immediately south-east of the old fort.

The group of three dykes, half a mile south-west of Cauldshiels Hill, has been found to consist of riebeckite-trachytes, wherefore their connexion with the Eildon suite of intrusions may be taken for granted.

The various dykes of the district will now be dealt with briefly under the respective headings trachyte, porphyry, felsite, and quartz-porphyry.

Trachyte.—Two purplish-pink trachytic dykes cross the main road north-west of Earlston. They contain phenocrysts of albite, surrounded by orthoclase, in a trachytic ground-mass. They resemble the White Hill sill very closely.

The Cauldshiels Hill dyke is a trachyte, composed of sanidine-laths with beautiful trachytic structure, and an occasional sanidine-phenocryst. Limonite replaces some of the felspar-laths, and is also present in grains. There can have been very little, if any, ferromagnesian mineral present originally.

The riebeckite-trachytes, half a mile south-west of Cauldshiels Hill, contain large kaolinized felspar-phenocrysts in a mottled, fine-grained, purplish, trachytic ground-mass of sanidine-laths, numerous tiny fresh riebeckite-prisms, and interstitial quartz. Towards the centre of the largest dyke the structure approaches the orthophyric.

Porphyries.—On the shores of Cauldshiels Loch are three porphyry-dykes which strongly resemble the trachytes just described. They are greatly altered, and contain only kaolinized felspars and limonite-pseudomorphs, possibly after riebeckite.

Felsites.—A beautifully-banded felsite occurs as a dyke at the top of Rhymers Glen, close to the Birkhill Shales. The margin which abuts against Silurian greywacke is fine-grained and spherulitic. Then follow alternate pale and dark-brown bands, the latter opaque under the microscope. Towards the centre the dyke is coarser, and presents an irregular fracture. Occasional microphenocrysts of altered felspar occur in the fine-grained felsitic base, which, under crossed nicols, shows patchy devitrification. Numerous quartz-veins traverse the dyke.

Quartz-porphyries.—The dyke intruded in the Chiefswood neck consists of small quartz and orthoclase-phenocrysts in a compact pinkish-brown matrix. The quartz-phenocrysts give rounded or square sections, and are subordinate to those of orthoclase. The latter are altered rectangular aggregates of muscovite, calcite, and a little quartz. The ground-mass is a microcrystalline aggregate of quartz, orthoclase, and some limonite.

A long quartz-porphyry dyke, lying north-west of Whitelaw Hill, contains large phenocrysts of deep-green pleochroic soda-pyroxene, kaolinized felspars, and idiomorphic quartz, in rectangular and hexagonal sections.

A 4-foot dyke, branching like a tuning-fork on the northern shore of Cauldshiels Loch, carries phenocrysts of kaolinized felspar and corroded quartz, the latter containing numerous inclusions of ground-mass. Irregular patches of limonite probably represent some decomposed ferromagnesian mineral.

A large dyke extending across the Cauldshiels Loch is very similar, and shows large, columnar, idiomorphic phenocrysts of sanidine which can be picked out intact. These are carried in a red ground-mass.

V. The Necks.

The Chiefswood neck is oval. Its larger diameter is a mile and three-quarters long, and ranges north-east; the smaller measures three-quarters of a mile.

It extends from Melrose well up into the moorland country, about 700 feet above sea-level. It is in contact with Silurian strata, except along its south-eastern boundary, where, as already stated, Upper Old Red Sandstone still remains.

The materials of the vent are exposed in Huntly Burn and in its three tributaries coming from the high ground on the south. They consist here of decomposed yellow clay, well bedded near the margin of the neck, and dipping inwards at about 30°. The junction with the Silurian greywacke is clearly visible in Rhymers Glen, about 20 yards below the lowest waterfall.

There are plenty of quarries in the neck where fresh agglomerate can be examined. The largest lies close to the railway-station, and provides building-stone for Melrose. The agglomerate seen in these quarries is a coarse accumulation of angular fragments up to 6 and 9 inches in diameter, with finer débris furnishing a matrix. The fragments recognized were:—

Greenish and grey micaceous shales. Grits and greywackes.	} Silurian.
Dark red sandstone.	Old Red Sandstone.
Flesh-coloured quartz-porphyry.	
Hard purple porphyry.	
Pink trachytes, similar to the Eildon trachytes.	
Amygdaloidal greenish basic glass.	
Olivine-basalt.	

The Little Hill neck is dealt with in this paper, on account of its occurrence within the Eildon complex, otherwise its basic constitution would exclude it from consideration here. The main rock is a plug of fine-grained non-porphyritic basalt stained by limonite, and often brecciated. This basalt consists of basic plagioclase, with fluxional arrangement and zoned with a fair proportion of orthoclase and abundant olivine in small granules.

An associated rock at the western end of the hill is closely allied to the Markle type of basalt. Phenocrysts of basic labradorite (60 to 70 per cent. anorthite) and decomposed olivine lie in a ground-mass of labradorite-laths associated with much limonite. On the two sides of a wall at the western end of this composite plug an ash occurs, containing small fragments of basalt, trachyte, greywacke, and shale. Small dykes are seen penetrating the ash from the adjoining plug.

The Little Hill neck is bounded on the west by sedimentary rocks of Silurian age, but on the north is in contact with a narrow band

of trachytic rock, fine-grained at its margin, although it becomes coarser away from the junction.

The contact of the trachyte with the Silurian rocks is exposed near the path; but, owing to the striking similarity of the rocks in colour and texture, is most difficult to locate. The Silurian rocks consist of much-indurated coarse and fine bands, greatly contorted and crumpled, which seem to have been pushed aside and diverted from their normal strike.

A small neck occurs in a ravine between the 800- and 900-foot contours, south-east of Rhymers Glen. The country rock in its immediate neighbourhood consists of much-shattered red shale and greywacke. The neck is filled, partly by a bright pink non-porphyritic vesicular felsite saturated with limonite, and partly by a breccia of angular fragments of a pink igneous rock and some bits of sediment in an igneous matrix.

There are but few exposures in the Faldonside Moor neck. Hillocks of medium-grained ash exist, which in their easterly extension contain numerous fragments of red honeycombed sandstone. The microscope shows a little sedimentary material in the main ash, with pumiceous and glassy igneous rocks, porphyritic and non-porphyritic trachytes, and, most interesting of all, a fresh piece of riebeckite-felsite, containing green-brown biotite, exactly like the felsites of the upper part of Eildon Wester.

VI. Summary.

The following are the main results of my recent study of the district:—

(1) The recognition of the Little Hill basaltic neck within the Eildon Hill complex, the acid rocks of which it almost certainly pierces.

(2) The extension of Mr. Barron's record of riebeckite. He found this mineral in the Eildon Hills, and suspected its former presence in the Black Hill. It has now been found fresh in the latter, as also in three trachytic dykes half a mile south-west of Cauldshiels Hill, and in a block in the Faldonside Moor neck.

(3) The recognition of a quartz-porphyry sill in the Eildon complex and a quartz-porphyry dyke in the Chiefswood neck; also the realization that quartz is an important mineral in the Eildon complex as a whole, and that the main rock-type occurring there is felsite.

(4) The proof that, if nepheline occurs in the Eildon complex, it must be very rare.

(5) The fact that these rocks may be regarded as a link between the phonolites and trachytes of the same age south-east of Hawick[1] and those of East Lothian,[2] already so well known. They cannot

[1] H. J. Seymour, 'Summary of Progress for 1900' Mem. Geol. Surv. 1901, p. 164.

[2] 'The Geology of East Lothian' Mem. Geol. Surv. Scot. 2nd ed. (1910) p. 127.

lay claim to being phonolites themselves, as has been hitherto thought, but are closely allied. Their content of alkali is high. Soda-bearing minerals, such as riebeckite, ægirine-augite, primary albite, and soda-orthoclase, are well developed and play an important part. Only a felspathoid is wanting to complete the analogy.

I wish to take this opportunity of expressing my thanks to Dr. Peach, Dr. Flett, and Mr. E. B. Bailey for much valuable advice and assistance during the progress of the work, and also to Mr. G. W. Tyrrell for the loan of rock-sections.

EXPLANATION OF PLATES XLI–XLIII.

Plate XLI.

[Except in one case, the slides belong to the Author's collection.]

Fig. 1. Porphyritic sanidine-trachyte from the sheet below North Hill. Ordinary light, × 32 diams. (Slide No. 21*b*.) The figure shows porphyritic sanidine-crystals in a ground-mass of orthoclase-laths and limonite. (See p. 307.)

2. Fine-grained riebeckite-felsite from the southern slope of Wester Hill, 100 feet below the summit. Ordinary light, × 37 diams. (Slide No. 14.) The figure shows dark patches of riebeckite in a fine felsitic ground-mass. (See p. 308.)

3. Augite-olivine-trachyte from near the summit of Eildon Mid Hill. Ordinary light, × 18 diams. (Slide No. 14, Forbes Collection, Hunterian Museum, Glasgow.) The figure shows subidiomorphic crystals of ægirine-augite and small granular olivines in a mass of alkali-felspar. (See p. 309.) From a slide kindly lent by Mr. G. W. Tyrrell.

4. Orthophyric riebeckite-trachyte from the northern slope of Mid Hill. Ordinary light, × 37 diams. (Slide No. 73.) The slide shows stumpy crystals of alkali-felspar in interstitial plates of riebeckite. (See p. 309.)

5. Quartz-trachyte from Bemerside Quarry. Crossed nicols, × 37 diams. (Slide No. 49.) The figure shows orthoclase-laths arranged in marked parallelism with interstitial patches of quartz. (See p. 306.)

Plate XLII.

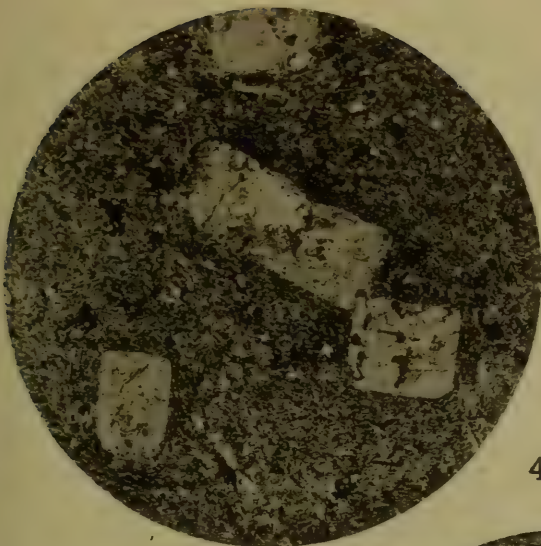
Fig. 1. Sketch-map of the Eildon Hills, on the scale of 6 inches to the mile, or 1 : 10,560. The broken lines drawn between the main rock-types do not represent definite geological boundaries, but have been inserted merely in order to give a general idea of the distribution of the types and the probable structure of the ground.

2. Section, on a horizontal and vertical scale of 6 inches to the mile, drawn across the above map, along the line AA.

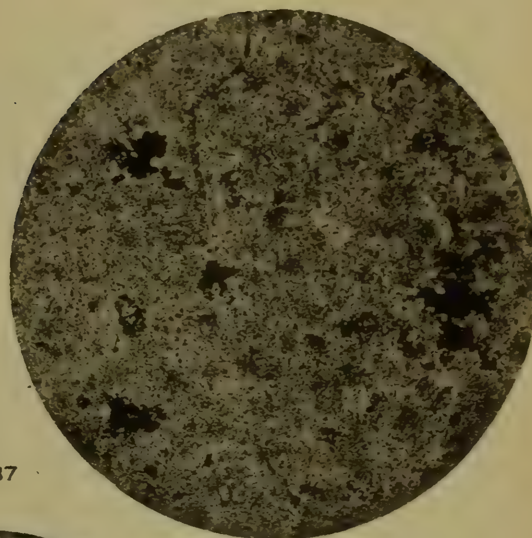
Plate XLIII.

General map, on the scale of 1·5 inches to the mile, or 1 : 42,240, showing the position of the various sills, dykes, and necks described in the paper, and their relations to the Upper Old Red Sandstone.

1. × 32

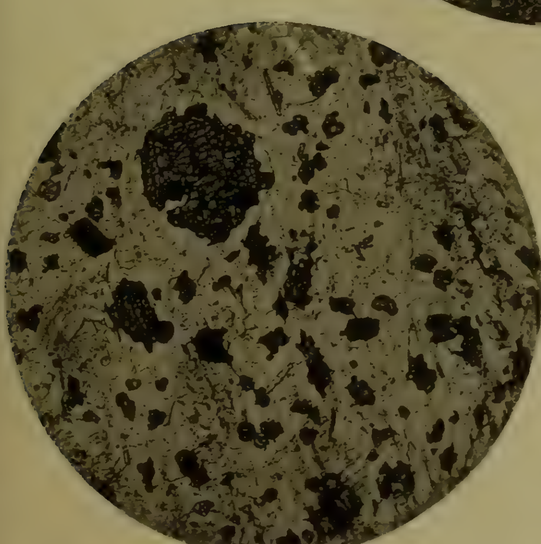


2. × 37

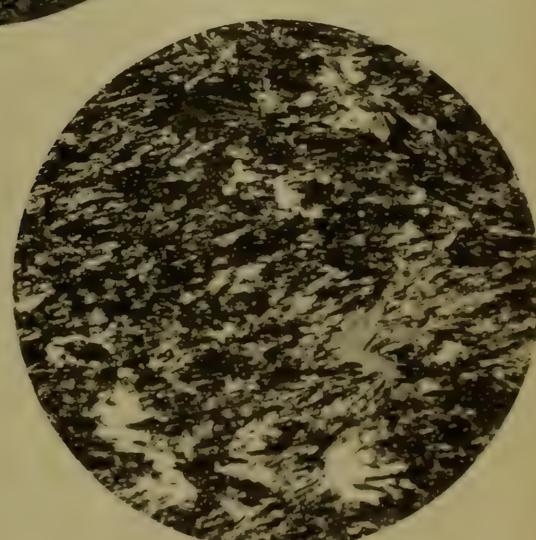


4. × 37

3. × 18



5. × 37



R. W. McR., Photomicro.

Bemrose, Collo., Derby.

TRACHYTES AND FELSITES FROM THE EILDON HILLS.

Pl. XLII.

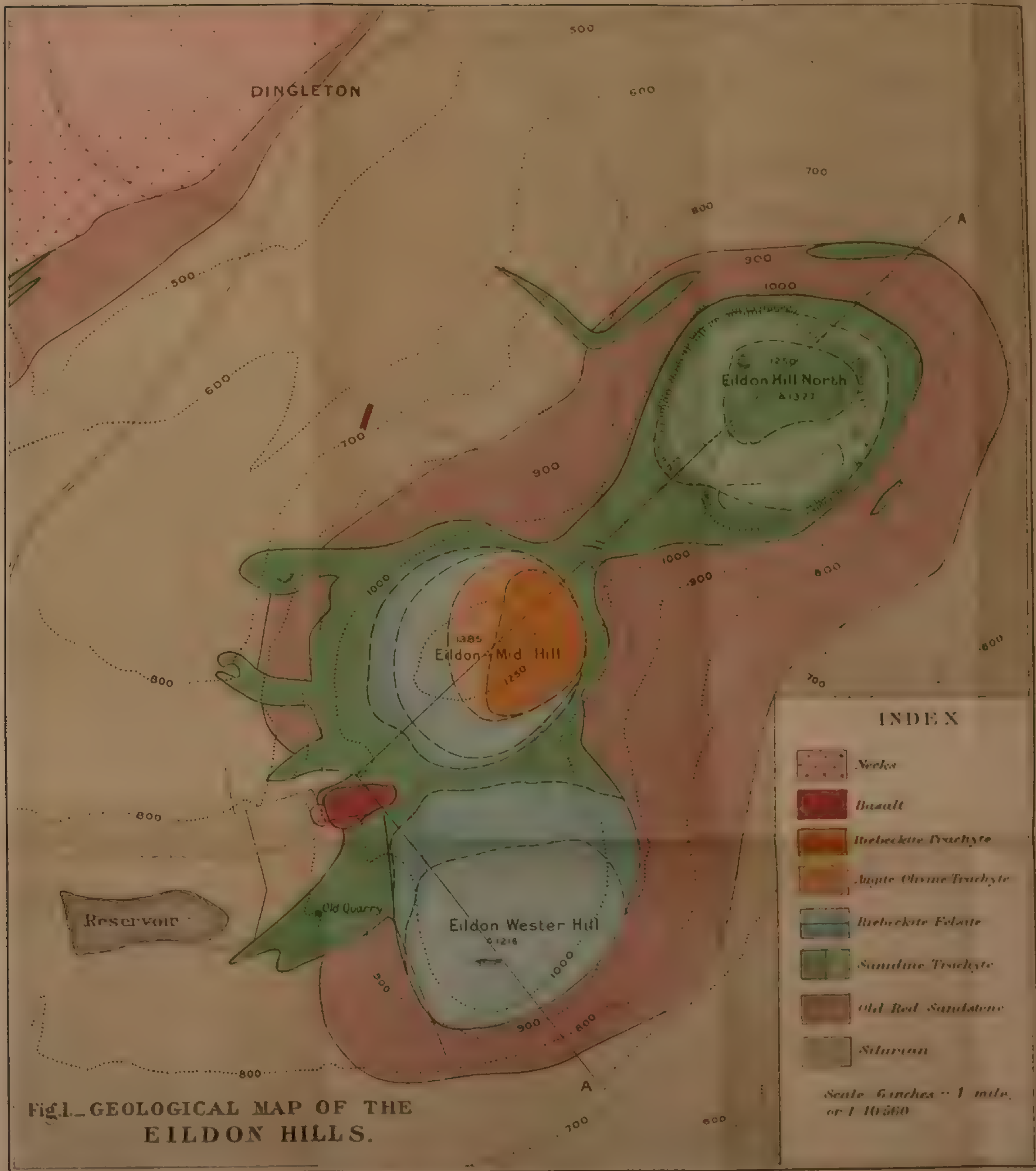
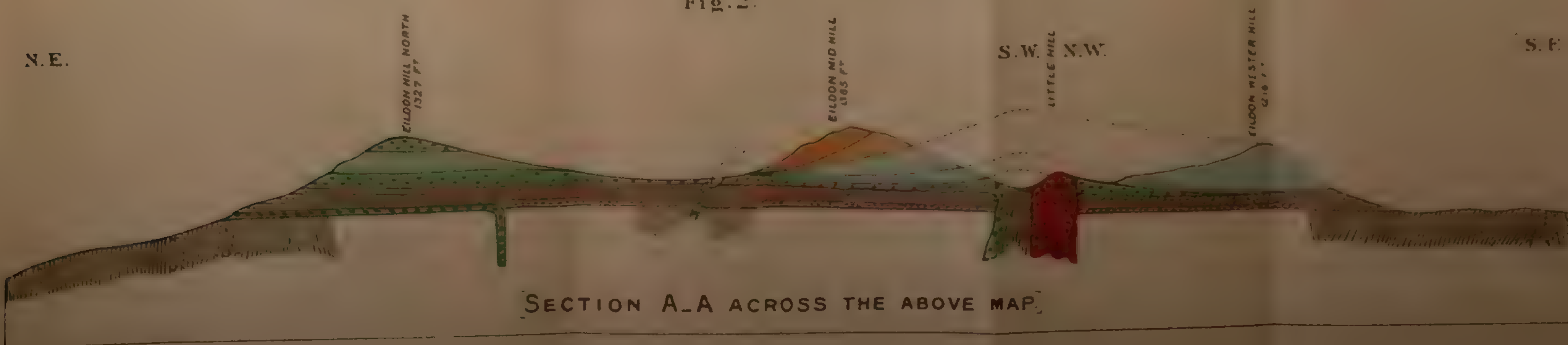
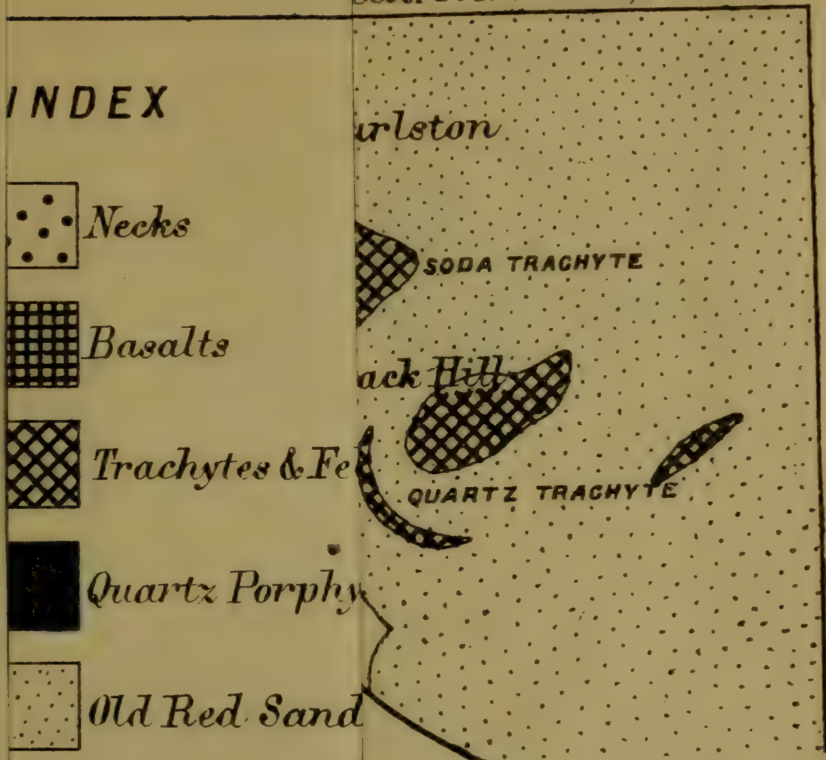


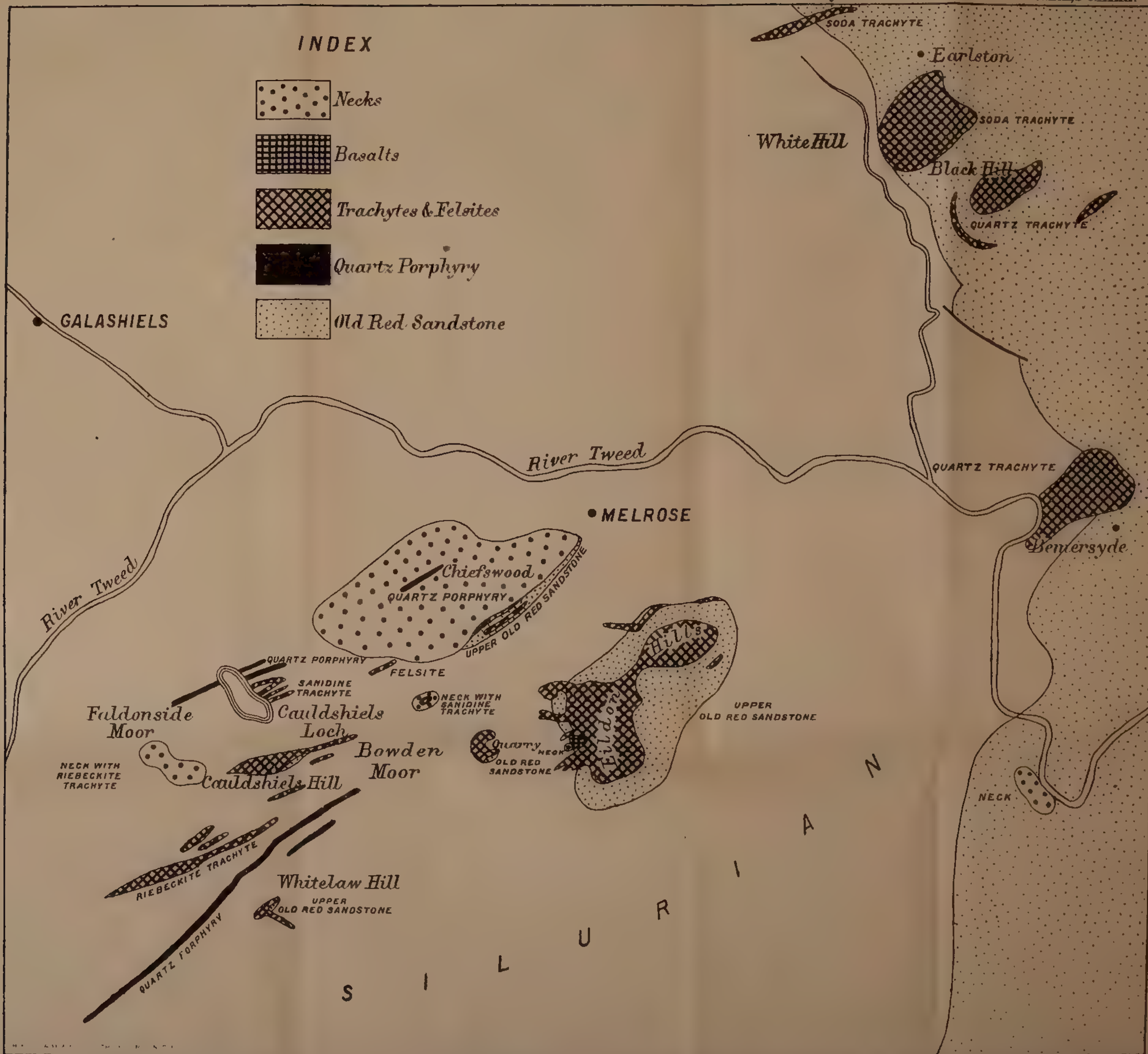
Fig.1._GEOLOGICAL MAP OF THE EILDON HILLS.

Fig. 2.



SECTION A_A ACROSS THE ABOVE MAP.


INDEX
Necks
Basalts
Trachytes & Fe
Quartz Porphy
Old Red Sand
rlston
SODA TRACHYTE
ack Hill
QUARTZ TRACHYTE



MAP SHOWING THE DISTRIBUTION OF THE IGNEOUS ROCKS AND THE OLD RED SANDSTONE IN THE NEIGHBOURHOOD OF MELROSE.
[SCALE: 1 MILE = 1·5 INCHES, OR 1:42240.]

DISCUSSION.

Prof. W. W. WATTS remarked on the peculiarity of the soda-bearing rocks described by the Author, in that they carried riebeckite and ægirine, but apparently no nepheline. He asked how far the connexion shown in the section between dykes and sills was supported by field observations.

Mr. W. CAMPBELL SMITH commented on the very wide sense in which the term 'trachyte' was used in the paper. He thought that many of the rocks mentioned were equivalent to those described by Dr. Prior as 'phonolitic trachytes,' while others containing more ægirine-augite and olivine might be acid members of the 'trachydolerite' group. Dr. Prior had described closely similar rocks from British East Africa and from the Antarctic.

He asked whether it was possible to determine the exact nature of the olivine in these rocks. The presence of fayalite in relatively-acid rocks, rich in iron-oxides and poor in magnesia, had been recorded recently, and further records of this mineral would be interesting.

Dr. J. V. ELSDEN said that particular interest attached to the rock described by the Author as olivine-trachyte, which appeared to be a highly specialized type and one that, if consolidated under plutonic conditions, might have been expected to produce a rock something like kentallenite. He regretted the necessity for applying the term 'trachyte' to these rocks, all of them being intrusives. He congratulated the Author upon her careful and detailed work in this area, which in some respects recalled certain features of the Christiania district.

Dr. J. W. EVANS referred to the different use of the term 'trachyte' in Germany and in the United Kingdom. In Germany the essential difference between a trachyte and an orthoclase-porphyry or orthophyre was formerly one of geological age and was now one of degree of alteration, and there was no objection to applying the former term to an intrusive rock. On the other hand, although a few British authors made the structure the criterion, as the Author had done, the great majority undoubtedly restricted its use to volcanic rocks. He was, however, doubtful whether such a restriction could be logically defended.

The AUTHOR, in reply, indicated on the sections those portions of the area that could be mapped with accuracy, and those that were largely covered with screes. She had detected a mineral resembling fayalite in some of the acid trachytes: it forms small spherulitic growths with glass as interstitial matter. She added that petrographical nomenclature was always a most difficult matter, and presented ample scope for differences of opinion; but she had tried to do the best that she could with existing rock-names. In conclusion, she thanked the Fellows present for the kind reception given to her paper.

13. *On the* LOWER JAW *of an* ANTHROPOID APE (*DRYOPITHECUS*) *from the* UPPER MIOCENE *of* LÉRIDA (SPAIN). By ARTHUR SMITH WOODWARD, LL.D., F.R.S., Pres. G.S. (Read April 29th, 1914.)

[PLATE XLIV.]

REMAINS of the Anthropoid Apes are so rare among fossils, that every new specimen is worthy of special description and discussion. I therefore offer to the Society some account of the fourth known example of the mandible of *Dryopithecus fontani*, which has been kindly lent to me by Prof. Luis M. Vidal, of Barcelona. It was found by Señor José Colominas near Seo de Urgel, Province of Lérida (Spain), in a deposit usually ascribed to the Upper Miocene; and, as already observed by Prof. Vidal,[1] the specimen is of unusual interest, on account of its occurrence in association with the *Hipparion* fauna. The jaws of the same species previously discovered in France,[2] are from Middle Miocene formations; while the only traces of the great Apes of a later date hitherto found in Europe are a few teeth from the Bohnerz of Würtemberg and the well-known femur from the Sands of Eppelsheim (Hesse-Darmstadt).

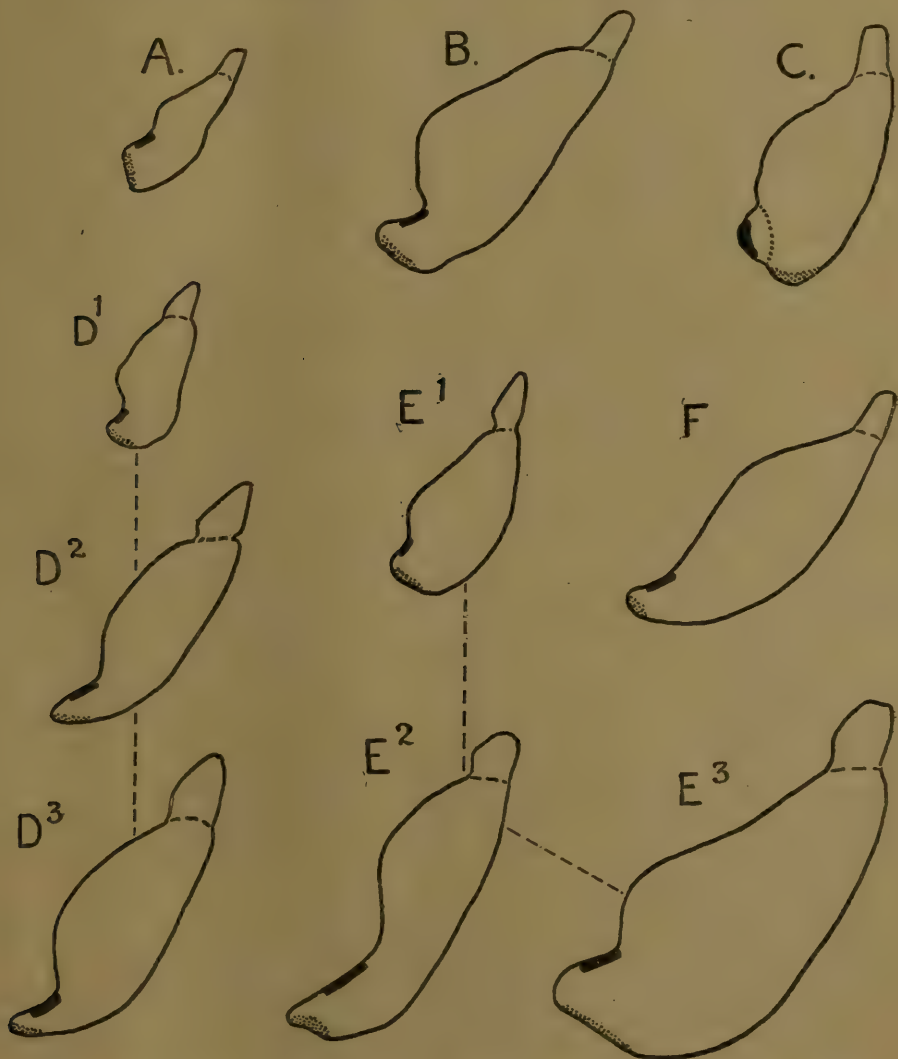
The new specimen (Pl. XLIV) comprises the greater part of the left mandibular ramus and the lower half of the symphysis, with the three molars well preserved and the roots of the fourth premolar broken in the socket. The pattern of the molars and the steepness of the symphysis determine the generic position of the fossil; while the proportions of the bone and the characters of the molar teeth are so closely similar to those of the specimens of *D. fontani* from the type-locality, that (as already recognized by Prof. Vidal) it can only be referred to this species. The outer cusps of the molars are more worn than the inner cusps in the usual Ape-fashion (Pl. XLIV, fig. 1); and each antero-external cusp (protoconid) is flanked by the short cingulum characteristic of the genus (Pl. XLIV, fig. 3). The enamel is perfectly smooth, and the only crimping that might produce a small secondary cusp occurs between the two inner cusps on the third molar. The first molar

[1] L. M. Vidal, 'Nota sobre la Presencia del *Dryopithecus* en el Mioceno Superior del Pirineo Catalán' Bol. R. Soc. Espan. Hist. Nat. 1913, pp. 499–507.

[2] E. Lartet, 'Note sur un Grand Singe Fossile qui se rattache au Groupe des Singes Supérieurs' C. R. Acad. Sci. Paris, vol. xliii (1856) pp. 219–23, with plate; A. Gaudry, 'Le Dryopithèque' Mém. Soc. Géol. France, Paléont. No. 1 (1890) pp. 1–11 & pl. i; E. Harlé, 'Une Mâchoire de Dryopithèque' Bull. Soc. Géol. France, ser. 3, vol. xxvi (1898) pp. 377–83, and 'Nouvelles Pièces de Dryopithèque & quelques Coquilles, de Saint-Gaudens (Haute-Garonne)' *Ibid.*, vol. xxvii (1899) pp. 304–310 & pl. iv. For notes on teeth of *Dryopithecus*, see also O. Abel, 'Zwei Neue Menschenaffen aus den Leithakalkbildungen des Wiener Beckens' Sitzungsb. k. Akad. Wissensch. Wien, Math.-Naturw. Cl. vol. cxi, sect. i (1902) pp. 1171–1207, with plate.

(*m. 1*) measures only 10 mm. in length, and is somewhat narrower than the others, with a relatively prominent antero-internal cusp (metaconid). The second (*m. 2*) and third (*m. 3*) molars measure 11 mm. and 11·5 mm. in length respectively, and the third tapers a little behind where the posterior cusp (mesoconid) is relatively large. Of the fourth premolar it can merely be stated that the roots prove it to have been as large as the same tooth previously described in *Dryopithecus fontani.*

Fig. 1.—*Cross-sections of the mandibular symphysis in various Primates; two-thirds of the natural size.*



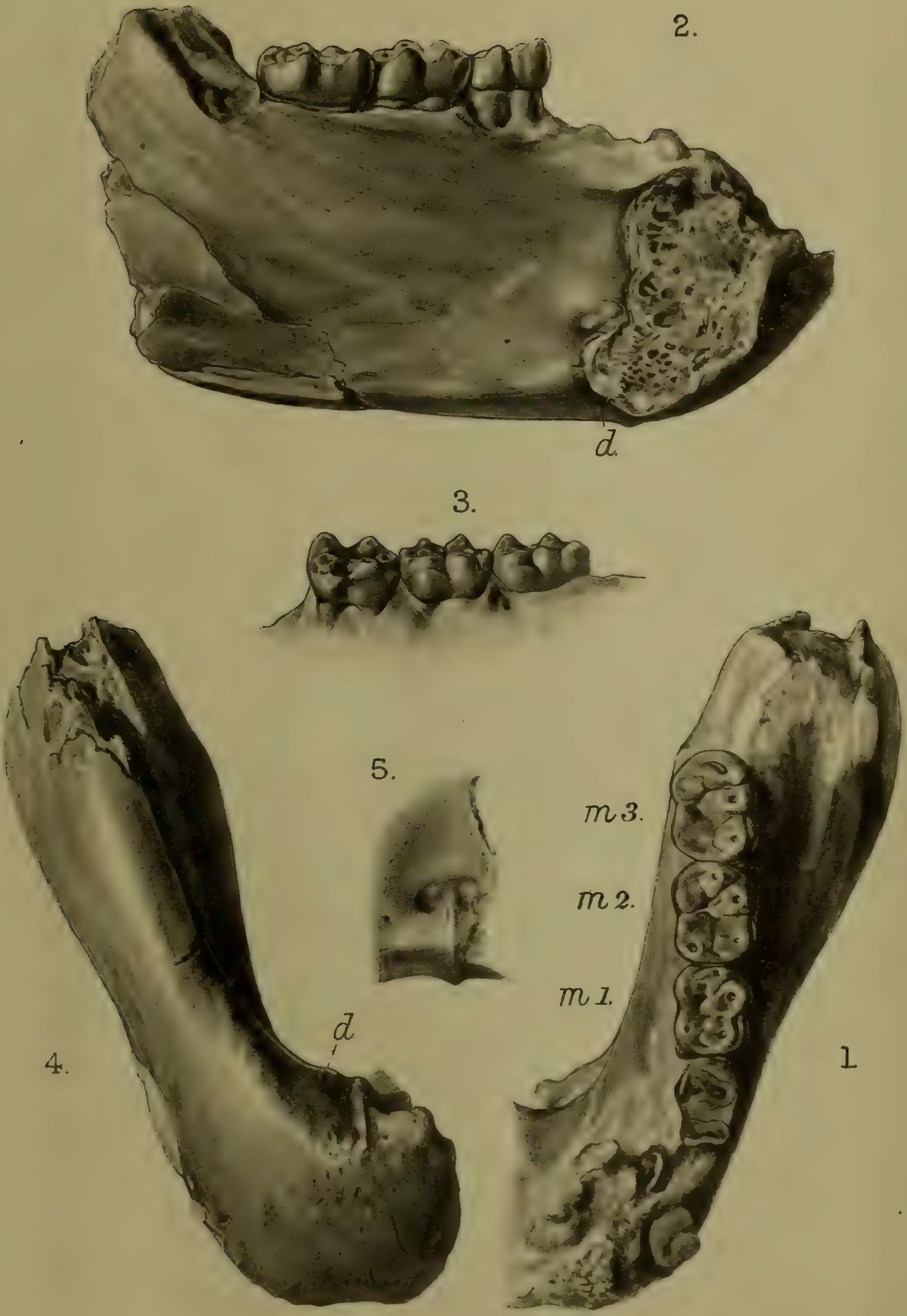
A. Adult *Mesopithecus*. B. Adult *Dryopithecus*. C. Adult *Homo heidelbergensis*. D.[1] Very young Chimpanzee, with (D[2]) young adult and (D[3]) adult female of the same. E.[1] Very young Gorilla, with (E[2]) adult female and (E[3]) adult male of the same. F. Adult *Eoanthropus dawsoni.*

[The dotted border marks the insertion of the digastric muscle, and the thick black border the origin of the geniohyoid.]

The bone is remarkably stout, and the symphysis, so far as preserved, is as heavy as that in the mandible described by Gaudry. As well shown in upper (Pl. XLIV, fig. 1) and lower (Pl. XLIV, fig. 4) views, the right ramus is broken away a little to the right of the median line; and, as seen in inner view (Pl. XLIV, fig. 2), the upper ledge of the symphysis is partly obscured by hard matrix. The inner face of the mandibular ramus is accidentally indented by crushing in the lower part, but the symphysis evidently retains its original shape. The smooth bone bears no clear mark of the floor of the mouth (mylohyoid muscle), but the limits of the insertion of the large digastric muscles are distinct (Pl. XLIV, fig. 4, and text-fig. 1 B, p. 317). The surface for the digastrics (*d.*), which is divided in the middle line by a slight ridge, truncates the lower border of the symphysis obliquely, being directed both backwards and downwards; and the vertical thickness of the muscle at this insertion must have been scarcely less than 10 mm., or at least a quarter of the maximum depth of the jaw. From the anterior border of the digastric insertion the plane of the outer face of the symphysis inclines upwards abruptly, without any horizontal extension below (Pl. XLIV, figs. 2 & 4). Above the posterior border of the digastric insertion the inner face of the symphysis is impressed with the usual deep pit (Pl. XLIV, fig. 5), in which the two ovoid hollows for the origin of the geniohyoid muscles are seen. Above this again the inner face of the symphysis rises sharply, but soon turns forward into the long ledge sloping upwards to the front teeth. As shown in the broken section (Pl. XLIV, fig. 2), the cancellous tissue of the bone is of very open texture, and the outer dense wall appears to be unusually thin.

The horizontal ramus of the mandible of *Dryopithecus*, with its symphysis, is therefore well known, and the two opposing views as to the systematic position of this Ape may now be reconciled in the light of recent researches. In his original description, Lartet considered that the apparent shortness of the jaw implied a face more nearly human than that of the existing Anthropoids, and he pointed to other features which suggested some approximation to Man. Gaudry, on the other hand, after studying a better-preserved specimen, decided that *Dryopithecus* was the lowest of the known Apes, and even approached the Macaques in the shape of the mandibular symphysis.

If the transverse section of the mandibular symphysis of *Dryopithecus* (text-fig. 1 B) be compared with that of the nearly contemporaneous Macaque, *Mesopithecus* (text-fig. 1 A, p. 317), a striking resemblance will indeed be noted. There is the same abrupt upward slope of the anterior face of the bone, and although the digastric insertion (dotted in the figure) is relatively smaller in *Dryopithecus* than in *Mesopithecus*, it is still very large for an Anthropoid. The digastric muscles in Macaques and other Monkeys are, in fact, excessively developed to undertake some of those functions of the floor of the mouth that are performed by the mylohyoid and geniohyoid muscles in the large existing



G. M. Woodward, del.

Bemrose, Collo., Derby.

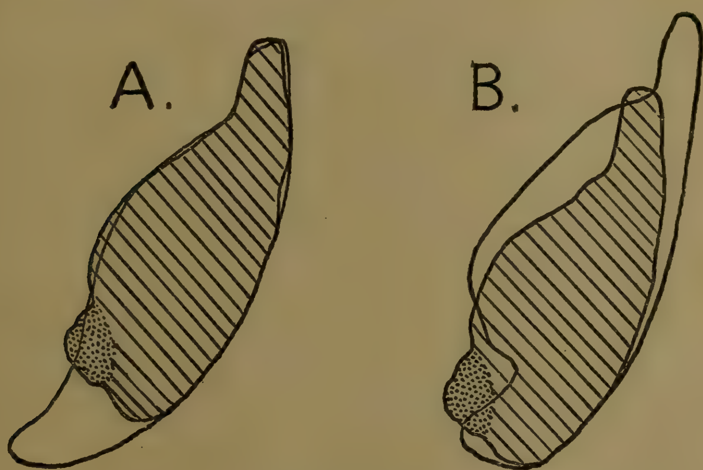
DRYOPITHECUS FONTANI *Lartet.*

Anthropoids.[1] In the latter the digastric muscles are more or less reduced, and *Dryopithecus* represents the stage in which the reduction had only just begun.

So far as the shape of its mandible is concerned, *Dryopithecus* is, therefore, a primitive type; and it is interesting to add that the relatively small size of its first molar is a character of the Macaques and other monkeys rather than of Anthropoids, although it is observable in some Gibbons.

A comparison of the mandibular symphysis of *Dryopithecus* with that of the existing Chimpanzee, Gorilla, and Orang, shows that it is also of a generalized type. In adult individuals of

Fig. 2.—*Cross section of mandibular symphysis of* Homo heidelbergensis (*shaded*), *superposed* (A) *on that of* Eoanthropus dawsoni (*outline*) *and* (B) *on that of* Dryopithecus fontani (*outline*); *natural size. Secondary bone at the origin of the geniohyoid muscles dotted.*



these Apes, the lower border of the symphysis is extended backwards either into a slender bony flange (text-fig. 1 D^2, D^3, & E^2, p. 317) or into a very massive thickening (E^3); consequently, the anterior face of the bone does not slope abruptly upwards from the front border of the digastric insertion, but only turns upwards after a more or less marked horizontal extension. In other words, the bony chin is antero-posteriorly elongated. In newly-born individuals of all these Apes, however, there is no such elongation or extension, and the anterior face of the symphysis (text-fig. 1 D^1 & E^1) slopes upwards almost as abruptly as in *Dryopithecus*. The Miocene Ape may, therefore, have been a common ancestor of the existing Apes in question.

The generalized character of the mandibular symphysis of *Dryopithecus* is still further emphasized when comparison is made with that of the oldest known species of *Homo* (*H. heidelbergensis*,

[1] M. Holl, 'Zur Morphologie des *Musculus digastricus mandibulæ* der Affen' Sitzungsb. k. Akad. Wiss. Wien, vol. cxxi, sect. iii (1912) pp. 107 & 109.

text-fig. 1 C, p. 317). Here it is necessary to remember that the pit on the inner or posterior face of the symphysis is nearly filled by secondary bone developed in the tendon at the origin of the genio-hyoid muscles. The postero-inferior outline to be compared is, therefore, indicated by a dotted line in the figure. Allowance being made for this, the resemblance is seen to be remarkably close—the anterior face in Heidelberg Man being only steeper, and the digastric insertion now facing more directly downwards.

The mandibular symphyses of *Mesopithecus*, *Dryopithecus*, and *Homo heidelbergensis* form, indeed, a gradational series (text-fig. 1 A, B, & C), in which there appears to be no place for a stage resembling that of any adult existing Ape. It is difficult even to understand how *Eoanthropus* (text-fig. 1 F) can be one of the series. If the outlines of *Eoanthropus* and *Homo heidelbergensis* be superposed (text-fig. 2 A, p. 319), it will be observed that the former differs from the latter in the specialization of the lower border towards that of a modern Ape. If the outlines of *Dryopithecus* and *Homo heidelbergensis* be superposed (text-fig. 2 B), the difference is seen to lie mainly in the reduction of the tooth-bearing region in the latter. On theoretical grounds, the second form of reduction seems the more likely to have taken place.

Hence, so far as the mandibular symphysis is concerned, the Miocene *Dryopithecus* resembles the large modern Anthropoids no more closely than it agrees with the earliest known true Man. By slight changes in two different directions it may have passed into the one as readily as into the other.

EXPLANATION OF PLATE XLIV.

Dryopithecus fontani Lartet; left mandibular ramus and symphysis, natural size.—Upper Miocene; Seo de Urgel, Lérida (Spain).

Fig. 1. Upper view, showing crowns of molars.
2. Inner view, showing cross-section near symphysis.
3. Outer view of molars, showing cingulum.
4. Lower view showing symphysis and digastric insertion.
5. Inner view of symphysis, showing pits for origin of geniohyoid and genioglossal muscles. *d.* = insertion of digastric muscles; *m. 1–3* = molar teeth.

DISCUSSION.

Mr. R. B. NEWTON said that he was of opinion that the terms Pliocene and Miocene, or those of any of the other great periods, so frequently applied in palæontological research-work, were inadequate for accuracy, and that it was necessary to quote the particular stage of those rocks which had yielded the material described. He instanced the Pikermi Beds, which were often referred to the Lower Pliocene, whereas they belonged to the latest stage of the Miocene, known as the Pontian. To the same part of the Miocene would belong the specimen described by the Author, on account of its association with *Hipparion*.

14. *The* Ballachulish Fold *near the* Head *of* Loch Creran (Argyllshire). By Edward Battersby Bailey, B.A., F.G.S. (Read June 10th, 1914.)

[Plate XLV—Geological Map.]

The main features of the tectonics of the Loch Creran district have already been delineated in a paper dealing with a more extended region, and published in 1910 by the Geological Society of London.[1] The results of this earlier work, brought up to date, are epitomized in the map (p. 322), which will serve as an index of the relations of the district to neighbouring portions of Argyllshire and Inverness-shire.

The original mapping of lower Glen Creran was carried out by Mr. H. Kynaston and the late Mr. J. S. Grant Wilson. Before preparing the paper just cited, I visited the district on two or three occasions, once accompanying Mr. C. T. Clough, and at another time Mr. H. B. Maufe. Various alterations in the mapping were made as a result of these traverses, and it was found that the more essential structural features were readily determinable in the light of evidence furnished by the country to the north-east. At the same time, it was apparent from the first that anything like detailed knowledge could only be attained as a result of systematic re-examination, involving a considerable expenditure of time. A favourable opportunity for further work arose officially during the past season, when observations were made which seem worthy of record as an illustration of the complexity locally recognizable in the Highland Schists.

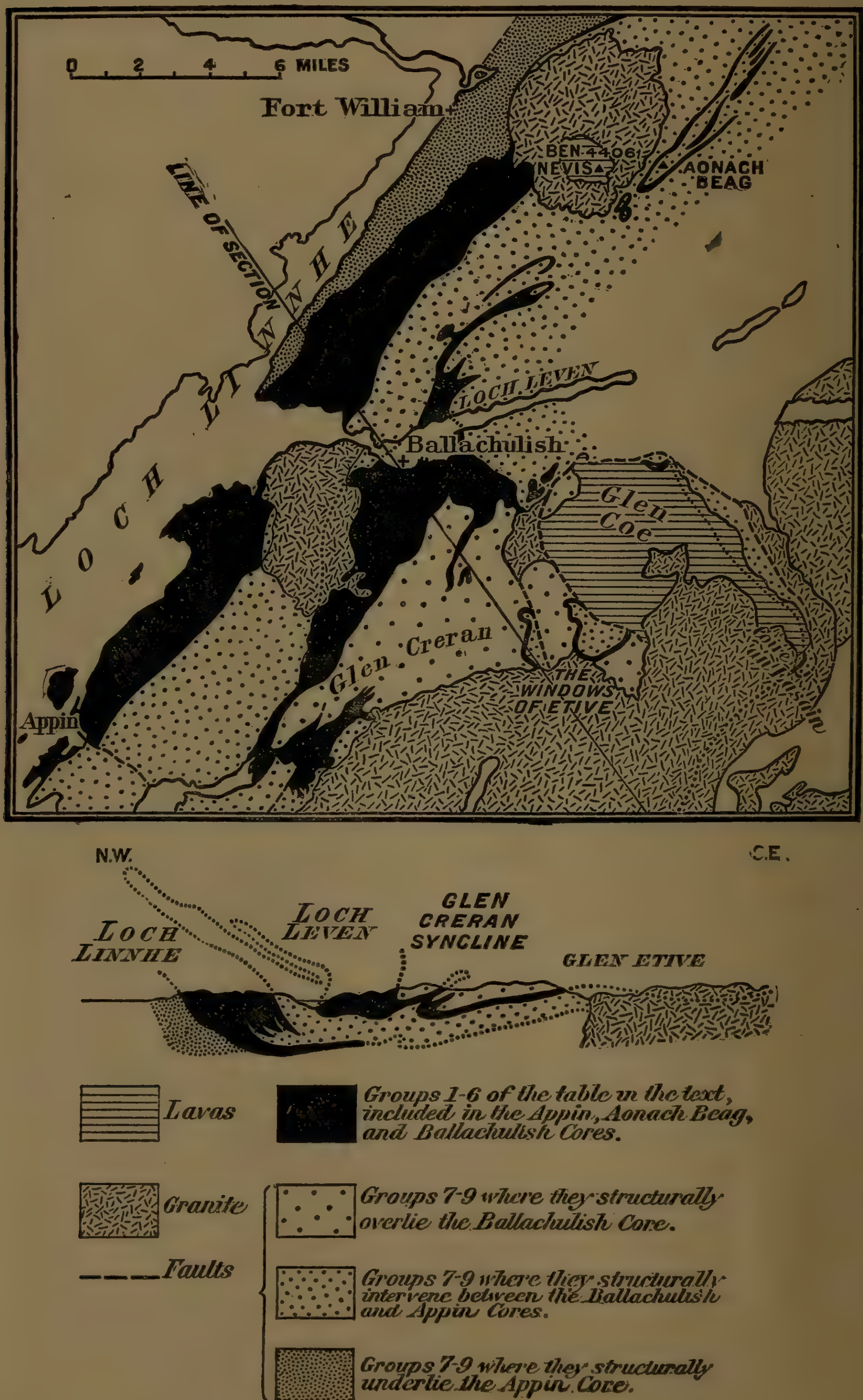
Two main difficulties are encountered in the field: there are many slides (fold-faults), so many, in fact, that the original stratigraphical sequence has to be accepted from neighbouring districts; there is also intense contact-alteration, extending for about a mile and three-quarters from the Cruachan Granite, and masking original differences in certain of the rock-groups.

The following is the stratigraphical sequence; but, whether it should be read upwards or downwards, is uncertain:—

9. Eilde Flags and (according to Mr. R. G. Carruthers) other groups.
8. Glen Coe Quartzite.
7′. Banded Series. } Leven Schists.
7. Pelitic Schists. }
6. Ballachulish Limestone.
5. Ballachulish Slates (black).

[1] E. B. Bailey, 'Recumbent Folds in the Schists of the Scottish Highlands' Q. J. G. S. vol. lxvi, p. 586.

Map and section illustrating the tectonic structure of parts of Argyllshire and Inverness-shire.



4′. Striped Series (where separated). } Appin Quartzite.
4. Pebbly Quartzite. }
3 & 2. Appin Limestones (3) and Appin Phyllites (2).
1. Cuil Bay Slates.[1]

When they are mapped out in detail, it is found that Groups 2 to 6, taken together, have a continuous curving outcrop in the neighbourhood of Loch Creran, and that this outcrop separates an internal area of pelitic Leven Schists from an external area of much more quartzose banded rocks—also Leven Schists, but belonging to a different division of this group. The explanation of this has already been given, and is based upon the reading of sections at Loch Leven, Glen Coe, and Glen Etive, north and east of the district now described. It may be summarized as follows:—

The schists of this region are disposed in a great recumbent fold—the Ballachulish Fold—of which Groups 2 to 6 are taken as constituting the core—the Ballachulish Core. The pelitic Leven Schists of the interior outcrop overlie the Ballachulish Core, while the banded Leven Schists of the exterior outcrop underlie the same. The absence of a belt of pelitic Leven Schists immediately below the Ballachulish Core, corresponding to that above, is due to the presence of the Ballachulish Slide—a powerful fold-fault at the base of the Ballachulish Core. We must not, however, leave out of account an original difference of facies of the Leven Schists above and below the Ballachulish Core in the Loch Creran district: in the upper structural layer the Leven Schists are divisible into an immensely thick pelitic group, and a comparatively insignificant banded series; in the lower layer the pelitic group is still evidently thick, but the Banded Series seems to have swollen greatly at its expense, and now, so far at least as outcrop is concerned, is predominant. The banded part of the upper layer, and the pelitic part of the lower layer, it may be mentioned, both lie beyond the limits of the map (Pl. XLV).

Another fact determined on outside evidence is that the Ballachulish Fold gapes towards the north-west, and closes towards the south-east.

Two phenomena strikingly illustrated by the local evidence are:—

(i) The complexity of the slides affecting the Ballachulish Core, and the correlated quite exceptional occurrence of more groups towards the close of the fold, south-east of the River Creran, than towards the gape, north-west of the same.

(ii) The intense secondary refolding of the Ballachulish Fold, and the resultant sinuous outcrop of the Ballachulish Core.

These two phenomena will now be dealt with a little more in detail.

[1] Groups (1) & (9) do not occur in the Loch Creran district (Pl. XLV), but are met with in the wider region included in the index-map (p. 322). The uncertainty in regard to Group 9 does not affect the present district. Mr. Carruthers has given good reason for suspecting that various mica-schists, quartzites, and flags, which I have regarded as repetitions of the Leven Schists, Glen Coe Quartzite, and Eilde Flags, respectively, are stratigraphically distinct. A résumé of Mr. Carruthers's position has been published in the 'Summary of Progress for 1912' Mem. Geol. Surv. 1913, p. 52.

(1) The Slides.—Much the most important slide is the Ballachulish Slide, which has been traced for many miles through neighbouring districts. Locally, this slide has two branches, and such is the case where it crosses the northern margin of the map. Between the two branches at this point, there occur thick representatives of the Ballachulish Limestone (6) and Slates (5). It is well known that the Ballachulish Limestone, when intact, is roughly divisible into a dark-grey, or black, comparatively pure limestone, next the Ballachulish Slates, and a pale-grey, or cream-coloured, highly-impure calcareous division, next the Leven Schists. Of these two parts, only the pure black Limestone is preserved between the two branches of the Ballachulish Slide: the impure portion is cut out by the western, or lower, branch of the slide, which, as already stated, also eliminates the pelitic division of the Leven Schists (7). East of the eastern, or upper, branch of the Ballachulish Slide, occurs a folded complex of Appin Quartzite (4), Appin Limestone (3), and Appin Phyllites (2).

South of the stream which flows past the Post Office, only the lower branch of the Ballachulish Slide has been traced. Its effect is generally to bring the black Ballachulish Slates (5) into direct contact with the banded Leven Schists (7). Locally, as at the road beside Loch Creran, a thin band of dark Ballachulish Limestone (6) is interposed between the two.

On crossing Loch Creran, one can recognize at first only a single branch of the Ballachulish Slide. It brings Appin Quartzite (4) with sometimes a thin marginal layer of calc-silicate-hornfels, probably Appin Limestone (3), against banded Leven Schists (7).

A mile farther on there is a return to the conditions met with at the northern margin of the map. The Ballachulish Slide is double, and includes between its two branches black pure limestone and hornfelsed black slates, belonging respectively to the Ballachulish Limestone (6) and Slates (5). The two branches of the slide have been traced eastwards, until terminated by a powerful fault, which displaces their outcrop to Allt Buidhe. Both branches are found here, including between them an important belt of Ballachulish Limestone. This latter is, in places, black and still a limestone or marble; but elsewhere, especially where it turns northwards up hill from Allt Buidhe, it occurs as a thick mass of pale-greenish calc-silicate-hornfels, the baked representative of the impure calcareous division which normally separates the black limestone from the Leven Schists. The mapping of the two branches of the slide is only approximate in the vicinity of the stream, owing to the considerable cover of morainic material thereabouts. It is known, moreover, that in the more westerly exposures both Ballachulish Limestone and Appin Limestone occur, the former well seen immediately south of the stream, the latter actually in the bed of the same. The upper branch of the slide should, therefore, be drawn at this point in the middle

of what is now, for convenience, shown as a single limestone outcrop. As a result, the mapping on the two sides of the fault would be brought into closer agreement than at present. A revision, effected on these lines, would probably also indicate a less dentate outcrop for the slides, but the difference would merely involve changes of local import. The limestone (calc-silicate-hornfels, with some dark marble) in the eastern outcrops, exposed on the slopes north of Allt Buidhe, certainly belongs wholly to the Ballachulish Group.

After being obliterated for a little by the Cruachan Granite, the Ballachulish Slide reappears as a single structure. It swings round sharply to the west for a space, and its course is somewhat ill defined—owing to the difficulty of determining an exact line separating the contact-altered Striped Series (4′) from the Banded Series (7′). The difficulty is not nearly so marked, however, as would have been the case nearer Loch Creran, for the Leven Schists at this point, although banded with quartzose ribs, are in large measure pelitic grey mica-schists, already indicating an approach to the facies of the group as developed in the structural layer overlying the Ballachulish Core. Beyond this westward turn, the Ballachulish Slide is very easily traced, as it separates Ballachulish Slates (5) from the comparatively pelitic Banded Series (7′). For a short distance, a thickness of some 40 feet of calc-silicate-hornfels, representing part of the Ballachulish Limestone (6), separates the two.

Before reaching the granite margin, on the slopes of Glen Ure, the Ballachulish Slates fail, and the Ballachulish Limestone of the upper limb of the great fold comes directly into contact with the Banded Series on the south.

A point of very considerable importance is the occurrence of pebbly Glen Coe Quartzite (8) in association with the banded Leven Schists (7′) which occur here between the Ballachulish Slide and the Cruachan Granite. In the typical region the Glen Coe Quartzite is fine-grained; in the exposures now considered it is coarsely pebbly, with large grains of quartz and felspar. In this feature it resembles the Appin Quartzite (4); but, even so, there can be no possibility of mistaking the two rocks, for the Glen Coe Quartzite is interbanded with grey semipelitic material, towards its margins especially, and is linked inseparably with the banded Leven Schists—nor is it a case of mere mechanical intermingling, for many of the semipelitic beds carry quartz- and felspar-pebbles. It is interesting to recall that in Glen Strae, on the other side of the Cruachan Granite, a similar pebbly quartzite, in what is believed to be the same structural position with relation to the Ballachulish Slide, has already been assigned to the Glen Coe horizon.[1]

Only one other slide need be mentioned specially in this summary. It has been known for some years to extend about 5 miles north

[1] E. B. Bailey & M. Macgregor 'The Glen Orchy Anticline' Q. J. G. S. vol. lxviii (1912) p. 172.

of the district here described to Sgòrr a' Choise, near Ballachulish, and on this account may be termed the Sgòrr a' Choise Slide. In its northern extension it almost constantly lies some little way within the Ballachulish Core; but, for a short distance east of Allt Coire Mulrooney, it constitutes the actual boundary of the core bringing Ballachulish Slates (5) into contact with Leven Schists (7). South of Allt Coire Mulrooney, the Ballachulish Slates disappear on the north-west side of the slide, while the pale highly-impure portion of the Ballachulish Limestone is prominently developed on the south-east side. For a distance of over a mile south-west from Allt Coire Mulrooney, greatly thinned-out representatives of the Appin Quartzite (4) and Limestone (3) persist on the north-west side of the Sgòrr a' Choise Slide. The limestone is well exposed in Easan Diblidh, and in the burn at Fasnacloich; the quartzite is seen both here and in intermediate exposures. South-east of the Fasnacloich burn, the quartzite and limestone both fail, but a belt of Appin Phyllites (2) still continues, until it tapers out, half a mile farther on, in the heart of Ballachulish Slates (5). At this point the Sgòrr a' Choise Slide and the upper branch of the Ballachulish Slide run together, and are no longer traceable.

A glance at the map will show that the Ballachulish and the Sgòrr a' Choise Slides are complementary. Both cut out a considerable thickness of rock, the one in the lower, the other in the upper limb of the Ballachulish Fold. Where the Appin Phyllites (2) are bounded on each side by Ballachulish Slates (5), it is a fair presumption that the missing Appin Limestone (3) and Appin Quartzite (4) have been squeezed out to find a resting-place somewhere nearer the close of the fold. Even where the Ballachulish Slates are continuous, owing to the Sgòrr a' Choise Slide meeting the upper branch of the Ballachulish Slide, it seems necessary to supppose that an unknown amount of rock has been squeezed through the slates, and that these have come together again, effectually concealing the passage. It is in this manner that we can most readily account for the presence of Appin Quartzite, Limestones, and Phyllites in the outcrop of the Ballachulish Core west of the River Creran.

Two further observations may be recorded. By far the greater part of the Ballachulish Limestone of the upper limb of the Ballachulish Fold consists, in this district, of pale highly-impure calcareous schist (calc-silicate-hornfels east of the River Creran). This suggests that a branch of the Sgòrr a' Choise Slide may continue at or near the base of the limestone outcrop, cutting out the black pure portion which one expects to encounter next the Ballachulish Slates.

The other point is the occurrence of a narrow phyllitic outcrop, extending south from near the Post Office, for about three-quarters of a mile, in the heart of Ballachulish Limestone. It probably is merely a non-calcareous band interstratified in the limestone series, but it must be admitted that its characters recall those of some parts of the Appin Phyllites—a very heterogeneous group.

xplanation

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nd
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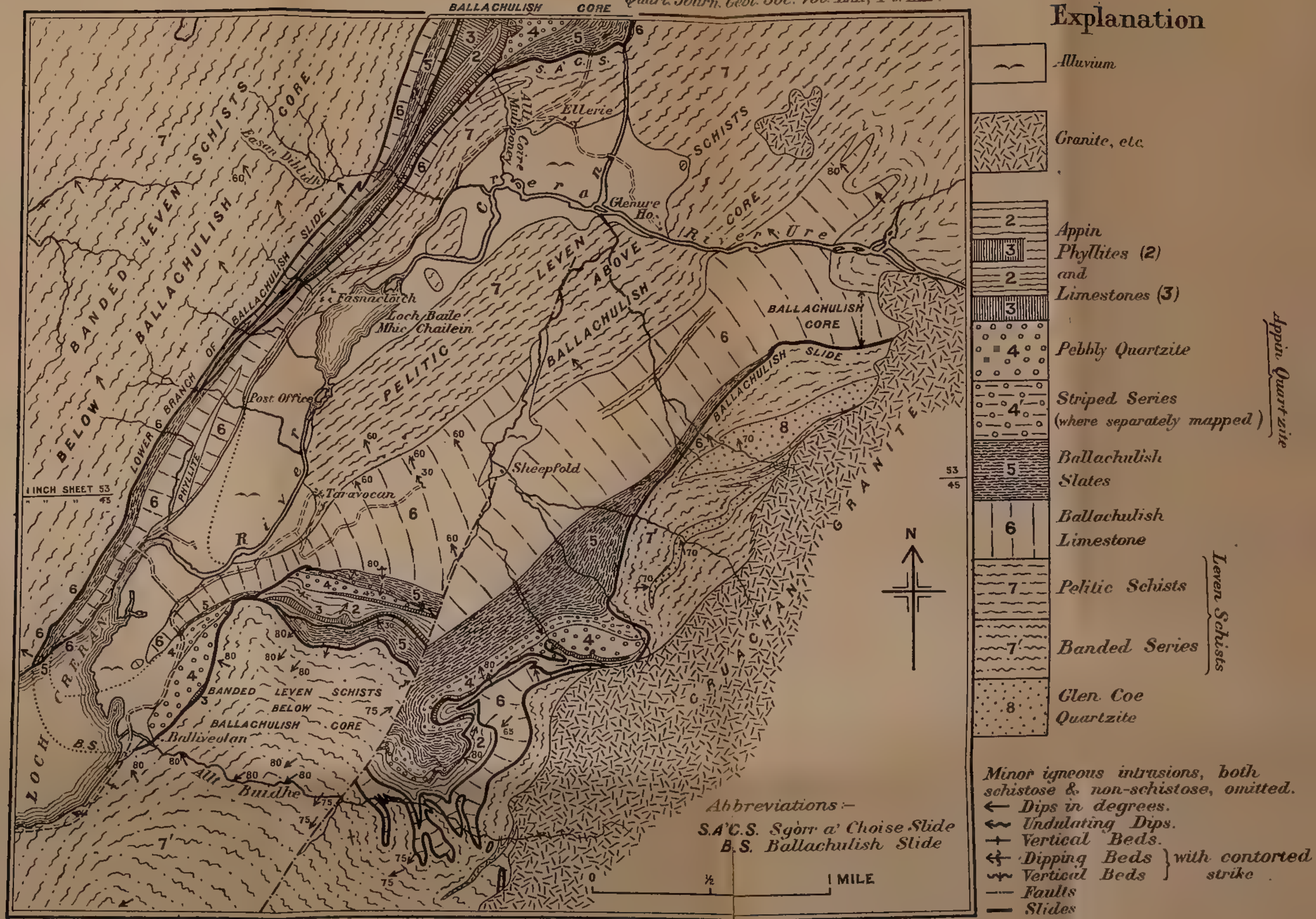
Appin Quartzite

Quart. Journ. Geol. Soc. Vol. LXX, Pl. XLV.



GEOLOGICAL MAP OF THE COUNTRY AROUND THE HEAD OF LOCH CRERAN

(2) The Refolding.—The secondary folding to which the Ballachulish Core has been subjected after its development is well illustrated in the sinuous outcrop of the core as shown on the map (Pl. XLV). Where the strike of the beds runs north-east and south-west, the dips are normally very steep and directed north-westwards. Even where the strike runs east and west, and the dips give an indication of the pitch of the secondary folding, they are still generally very high, and are directed more often towards the south than the north—the exact opposite of what might be expected. The pitch of the secondary folding is not, however, a very clearly-defined phenomenon, for there is a sudden swirl in the strike of the folding in the upper part of Allt Buidhe. All that can be said is that the secondary folding is very compressed, and of isoclinal type; and that the local evidence furnishes no clue as to which is the upper, and which the lower, side of the Ballachulish Core—a point which has been determined quite definitely, however, in neighbouring districts.

A feature of the geology noted already in previous publications[1] may be restated here. Between the River Creran and the Cruachan Granite, there are great numbers of small intrusions of basic igneous rock in the condition of hornblende-schist. They are distributed impartially on the two sides of the Ballachulish Slide, so that they must be of later date than the movement along this slide. Their metamorphic condition, however, shows that they have been affected by powerful movements; thus it seems probable that they antedate the secondary movements dealt with above.

EXPLANATION OF PLATE XLV.

Geological map of the country around the head of Loch Creran, on the scale of 2 inches to the mile, or 1 : 31,680.

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[1] E. B. Bailey & M. Macgregor, Q. J. G. S. vol. lxviii (1912) p. 178.

15. *On the* Relationship *of the* Vredefort Granite *to the* Witwatersrand System. By Frederick Willoughby Penny, B.Sc., F.G.S. (Read May 13th, 1914.)

[Plates XLVI & XLVII.]

Introduction.

The Vredefort Granite has always been considered as a member of that 'old granite' group which throughout the Transvaal and the Orange Free State is found emerging from beneath the Witwatersrand Beds. Although mineralogical differences could be observed from area to area, this grouping together was a matter of convenience, dictated by their stratigraphical position.

The first attempt to indicate the extent of the granite outcrop with any pretence of accuracy was made by Dr. F. H. Hatch in his Geological Map of the Southern Transvaal, published in 1897. With regard to the encircling sedimentary rocks, it is clear from the stratigraphical and lithological evidence that they are of Witwatersrand age—the southern rim of the basin of Witwatersrand rocks, the northern rim of which crops out along the Rand.

Several geologists who have visited the Vredefort area appear to have been struck by indications pointing to the intrusive nature of the granite into the Witwatersrand Beds. Thus Dr. Molengraaff in 1903,[1] arguing from the steep dip and overtilting of the surrounding strata, the occurrence in them of small enclosures of granite at some distance from the main outcrop, and the evidence of contact-metamorphism in the adjacent beds—particularly the production of corundum—proved it conclusively to his own satisfaction. But, in the following year, he was led to retract his views,[2] on considering evidence collected in the meantime from other parts of the Transvaal as to the non-intrusive relationship of this 'old granite' group to the Witwatersrand System. To argue, however, in this way from one area to another is to assume contemporaneity of intrusion as well as stratigraphical similarity, which is too hazardous an assumption. Any definite views held about one area should only suggestively bias the observer when dealing with another. This point has also been previously emphasized by Mr. C. B. Horwood.[3]

In the present paper evidence is brought forward to prove clearly the intrusive nature of the Vredefort Granite into the Witwatersrand Beds, based on an examination of the adjacent sediments and a detailed map of several miles along the contact, made in my spare time during a year's sojourn in the neighbourhood.

[1] Trans. Geol. Soc. S. A. vol. vi (1903) pp. 20–26.
[2] *Ibid.* vol. vii (1904) p. 115.
[3] Geol. Mag. dec. 5, vol. vi (1909) p. 467.

Locality.

The area to be described is situated in the Orange Free State, a few miles south of the Vaal River, on the north-east side of the Vredefort Granite outcrop. It has proved to be a particularly favourable locality for examination, because here for a considerable distance the granite abuts directly against some member of the Witwatersrand Series; while on the north, on the Transvaal side of the river, basic intrusions intervene to a greater or less extent.

Although, in a general way, the strike of the sedimentary beds gradually curves round so as to become tangential to the margin of the granite boss, the actual junction is far from being a simple curve. The area mapped is particularly noteworthy for the varying horizons of the Witwatersrand Beds with which the granite comes into contact, owing to the removal of varying amounts of the lower beds by the granite, and is further complicated by the profuse intrusion of basic rock.

The generic term diabase has usually been applied to these basic intrusions in the Witwatersrand Beds; and therefore, as a matter of convenience, it will continue to be used throughout this paper. A microscopic examination, however, shows—at any rate in the area under discussion—that this basic rock is alkaline and intermediate in composition, and should more correctly be termed a soda-porphyrite. It is holocrystalline, and consists principally of hornblende and felspar. The hornblende occurs in idiomorphic crystals, dark green and very pleochroic: there is no evidence that this hornblende is of secondary origin; it is too dark for uralite, nor does the shape of its sections suggest that it is derived from augite. Surrounding these crystals is a border of dark blue-green hornblende, in optical continuity with the main mass and of later growth; it is intermediate in composition, but near arfvedsonite, and also occurs in a second generation as minute blades in the groundmass (Pl. XLVI, fig. 1 *a*). The hornblende must have continued crystallizing quite late in the consolidation of the rock. The felspar is a medium oligoclase, usually rather decomposed and then crowded with epidote-grains: it is sometimes surrounded by an edging of orthoclase. Interstitial quartz and micropegmatite are common constituents (Pl. XLVI, fig. 1 *b*), and the orthoclase of the latter is in optical continuity with that surrounding the oligoclase-crystals.

Description.

Starting from the south-western end of the farm Vergenoeg (see map, Pl. XLVII), we find the lowest quartzite of the Witwatersrand System, W 1_a, forming a ridge that abuts against the edge of the granite. This is evidently the section mentioned by Dr. E. Jorissen [1]

[1] Trans. Geol. Soc. S. A. vol. vii (1904) pp. 156–57.

'on the farm Vergenoeg 220,' and described by him as follows :—

'The actual contact between the two rocks is exposed in a cutting connecting two hills, the one consisting of Orange Grove Quartzites, and the other of old granite. The Orange Grove Quartzites dip towards the granite, and are very much laminated at the contact, no doubt due to the tilting and the sliding of the beds. The granite, although much weathered, shows a strip of sericite-schist separating it from the quartzites.'

At the time of my visit, there was no cutting open exposing the actual contact. On passing north-westwards towards the Zyfer-fontein boundary, one notes that a thickness of diabase intervenes between the granite and the sedimentary beds. This is not at all an unusual phenomenon, for it occurs to a varying extent all round the granite margin. In this case the line of separation is remarkably sharp; no veins of the one igneous rock were observed to penetrate the other. Several isolated masses of well-bedded quartzite occur on the inner edge of the diabase, having apparently been wedged off from the main mass of quartzite at the time of the diabase intrusion. On the north, this quartzite-ridge and the diabase come to an end suddenly against a fault, which must be subsequent in age to the basic intrusion, and probably resulted at the time of the intrusion of the granite. Proceeding northwards, one observes the interesting phenomenon of the granite invading the Witwatersrand Beds; the quartzite (W1) is entirely absent, and the granite finds itself in contact with some part of the slates (W2) which overlie it, except for a narrow band of quartzite that for a short distance defines the margin of the granite. The slates, as also their continuation northwards and southwards, are to the eye considerably changed from their normal appearance of reddish or brownish-black, very ferruginous, flaggy beds; but their well-marked banding, and the coarse cleavage parallel to it, are still well preserved. Certain horizons are very rich in magnetite, and form prominent outcrops. In these magnetite-slates, thin bands composed almost entirely of radiating actinolite-crystals occur, separated by layers of magnetite with little or no actinolite visible to the naked eye. Under the microscope large crystals of somewhat decomposed staurolite were observed, frequently twinned, having clear edges but centres cloudy with opaque dust (Pl. XLVI, fig. 2); angular fragments of quartz and clear secondary felspar were detected in the ground-mass among the magnetite-grains. The slates are much shattered and faulted, as can be seen from the mapped outcrop of a narrow band of felspathic quartzite ($W2_b$) which occurs in the body of them. This band is very distinctive, and has been traced for some distance north-westwards, while its position relative to the granite margin affords a good idea of the amount of sedimentary beds absent at any point. Farther on, another lenticular mass of diabase intervenes at the margin of the granite, and the quartzite (W1) simultaneously makes its reappearance—first as a narrow band between the slate and diabase, then as a thicker contorted and faulted ridge, which finally develops into its normal thickness and continues up to the Parijs road, where it terminates

against a further mass of diabase. North of the Parijs road the quartzite (W1) is again absent, and the granite abuts against the actinolite-magnetite slate as before, a tongue of it penetrating into the sedimentary rocks and associated basic intrusions for a considerable distance.

So far, the granite has shown a remarkably sharp and regular margin towards the various rocks with which it has come into contact. From the map, one may presume that the diabase withstood the effect of the granite intrusion more successfully than the sedimentary rocks; that it has, in fact, formed some sort of a protection for them. Even so, the adjoining sedimentary beds are seen to have been removed to a considerable extent by the granitic intrusion. The evidence seems to point to this having been brought about by a process of stoping-away of the sedimentary rocks and their sinking to lower levels, rather than to direct absorption and assimilation of them by the granitic magma, since the composition and structure of the granite thus far has appeared to be uniform right up to its margin.

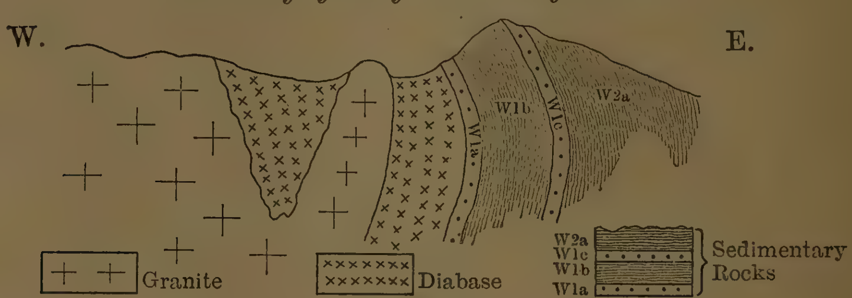
However, in this tongue of granite which penetrates into the sedimentary rocks and associated diabase for some distance, there is ample evidence of action and reaction between the acid and the basic magmas. At one spot the granite becomes a hornblende-granophyre, at another practically an aplite with a considerable amount of plagioclase, losing its ferromagnesian constituents and its characteristic large felspar-phenocrysts. In surface-specimens the felspar assumes a brilliant red colour, suggesting that the predominant felspar of the rock is orthoclase; but no determination could be made in the microsections, owing to the extent to which kaolinization had proceeded. Thin streaks of the acid magma are found veining the basic rock, which is here practically amphibolite. That the granite partly re-fused this amphibolite is shown by the presence of numerous dark patches of hybrid rocks embedded in the former, varying in size from quite small inclusions to masses several yards in diameter. Two such particularly large masses are indicated on the map. They are completely recrystallized rocks, consisting of small cloudy hornblende-crystals embedded in a very fine-grained ground-mass, which appears to have a felspathic base crowded with minute crystals of a decomposition-product like zoisite. A considerable amount of acid material has been introduced into this rock, as is proved by the presence of comparatively large fragments of pink orthoclase intergrown with quartz, evidently derived from the adjacent granite, corroded and penetrated by stringers of the hornblendic ground-mass (Pl. XLVI, fig. 3).

Farther north, the margin of the granite is defined by part of a really large intrusion of diabase. Usually, in the Witwatersrand Beds of this area, the basic dykes have intruded themselves along planes of weakness or junctions of slate and quartzite, and often preserve a nearly constant thickness and horizon for many miles. This intrusion, however, has burst through the sedimentary rocks,

intruded tongues along lines of weakness in them, caused extensive faulting, and broken through thick beds of quartzite at right angles to the strike, thereby completely isolating several large and small masses of quartzite and slate. In the middle of it, as indicated on the map, was found a small area of an amygdaloidal rock, containing many large amygdales, often tubular in shape, chiefly filled with quartz. The nature of the junction between this rock and the normal diabase is indefinite, and was difficult to ascertain; but the impression gained was that the diabase suddenly became amygdaloidal.

The case of the quartzite (W1) in contact with the diabase near the northern boundary of the farm 'Tweefontein' is interesting: it dips comparatively gently away from the granite, in contradistinction to the overtilted or nearly vertical dip which all the sedimentary beds invariably have hereabouts. This is explained as being due to a subsidiary granite intrusion into the diabase, the top of which comes to light in the middle of the diabase to the west of the quartzite-ridge; this must have forced the sedimentary beds outwards from the granite, thereby giving to its inner side a

Fig. 1.—*Quartzite-contact with diabase near the northern boundary of the farm 'Tweefontein.'*



curvature (fig. 1). When traced northwards the sedimentary beds gradually assume a vertical, and then an overtilted position.

This basic intrusion is a definite addition to the thickness of the strata above the granite, since no evidence of absorption of the sediments by it on any large scale was discovered. However, the remarkable regularity of the boundaries which the slaty members of the series exhibit towards the diabase, as opposed to the constantly faulted outcrops of the associated quartzite-bands, is suggestive of a certain amount of absorption by them. As a general rule, the moderate-sized intercalations do not even produce metamorphism visible to the naked eye in the slates adjacent to them. The extreme extent and nature of the metamorphism which they effect can be well studied in the masses of slate enclosed in the larger intrusions remote from the granite, as, for instance, on the farm 'Tweefontein.' While still preserving its banding and cleavage, the slate is changed to a pinkish-brown rock, somewhat phyllitic in appearance, which, under the microscope, is seen to consist of comparatively large flakes of sericite, roughly orientated, and

granules of quartz, the whole being deeply stained with limonite. No other minerals were observed. This is so different a rock from the staurolite-actinolite-magnetite slate found in contact with the granite, but derived from the same type of rock, that it is reasonable to assume that the latter variety is intimately connected with the granite intrusion, and has not been produced by the diabase.

The extent of the disturbance caused by this intrusion of diabase can be appreciated by tracing the band of quartzite (W3), which in the southern part of the area forms its eastern boundary. After being completely cut through three times by the diabase, north of the Parijs road it is duplicated, forming two parallel outcrops for a considerable distance, the one thrust behind the other.

Coming now to the correlation of these sedimentary beds, one can draw no exact parallel with those cropping out along the Rand; but it seems highly reasonable to assume that the division W1 corresponds to the Orange Grove Quartzite, W2 to the Water-Tower Slates, W4 to the Hospital Hill Slates, with the contorted magnetite-quartz band in the middle of it, and W5 to the Hospital Hill Quartzite. The vertical section appended to the map (Pl. XLVII) shows that two subsidiary quartzites (the lower one felspathic, and both somewhat impersistent) occur in the mass of W2; while W5 is made up of several alternating bands of quartzite and slate, with a thick mass of quartzite at the top. The total thickness of the beds to the top of W5 can approximately be estimated at 4800 feet.

Summary.

To sum up: In this paper it is maintained that the Vredefort Granite is intrusive, not only into the Witwatersrand Beds, but also into the basic intrusions associated with them. It is shown that along its margin the granite has removed—possibly by absorption, but more probably by overhead stoping, varying amounts of the sedimentary beds from point to point; that it has reacted with the basic intrusions in the sedimentary beds, with the production of hybrid rocks; that in one place a subsidiary intrusion of granite occurs in the middle of the diabase; and finally that the granite has induced a definite type of metamorphism in the adjacent slates, which is of a type distinct from that induced by the diabase.

With regard to the age of this granite, it has been suggested to me by Dr. Hatch that the diabase, which is sometimes amygdaloidal, may be genetically connected with the Ventersdorp Beds, in which case the granite would be of post-Ventersdorp age. In 1903, Dr. Molengraaff was impressed with the fact that the sediments surrounding the granite boss, up to and including the Pretoria Beds, were highly inclined, and, with the granite, were overlain by the practically horizontal Karroo Beds. Being of the opinion then that the steep dip of these beds was caused by the intrusion of the granite, he postulated a post-Pretoria–pre-Karroo age for this intrusion. I suggest, therefore, that the Vredefort Granite is, if not contemporaneous with, at least connected with the same epoch of igneous activity as, the Red Granite of the Northern Transvaal.

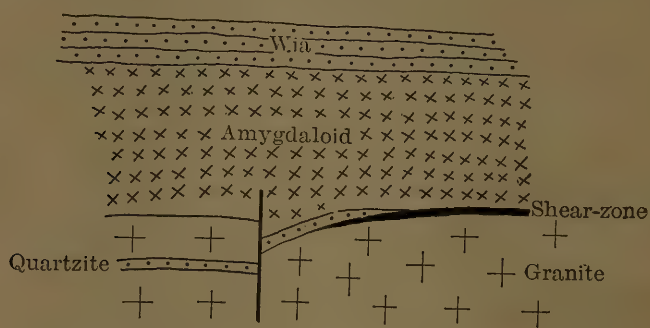
Postscript.

The margin of the granite a few miles to the north-west of the area described above, near the boundary of the farms 'Zandfontein' and 'Anna's Rust,' is also of interest in connexion with the relationship of the granite to the Witwatersrand Beds.

A certain thickness of amygdaloidal diabase is intercalated between the lowest Witwatersrand quartzite and the granite. A well-bedded strip of quartzite occurs along the inside edge of the amygdaloid, in a manner similar to that already described near the south-western boundary of the farm 'Vergenoeg'; it terminates against a small fault, on the other side of which its course is continued e n t i r e l y i n s i d e t h e g r a n i t e for some distance, its stratification and nearly vertical dip being perfectly maintained. Between the amygdaloid and the granite is a shear-zone, 10 yards or so broad, of vertically banded mica-schist, with inconstant bands and lenticular masses of quartz developed along planes parallel to the foliation.

[While this paper was going through the press, my attention was drawn to Dr. C. Sandberg's view of the age of the Vredefort granite, Geol. Mag. dec. 5, vol. v (1908) p. 559, with which my own conclusions appear to coincide. *F.W.P., Oct. 1914.*]

Fig. 2.—*Relationship of quartzite, diabase, and granite near the boundary of the farms 'Zandfontein' and 'Anna's Rust.'*



EXPLANATION OF PLATES XLVI & XLVII.

Plate XLVI.

Fig. 1 *a*. Quartz-soda-porphyrite, showing green hornblende, acid plagioclase, and quartz. Ordinary light. × 18 diams. (See p. 329.)

1 *b*. Quartz-soda-porphyrite, showing micropegmatite. Crossed nicols. × 18 diams. (See p. 329.)

2. Magnetite-actinolite-staurolite rock, showing well-formed crystals of staurolite with dark centres. Ordinary light. × 8 diams. (See p. 330.)

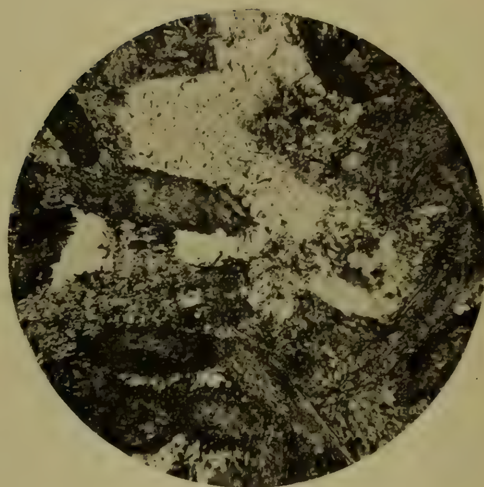
3. Basic rock with inclusions of granitic material. Ordinary light. × 18 diams. (See p. 331.)

Plate XLVII.

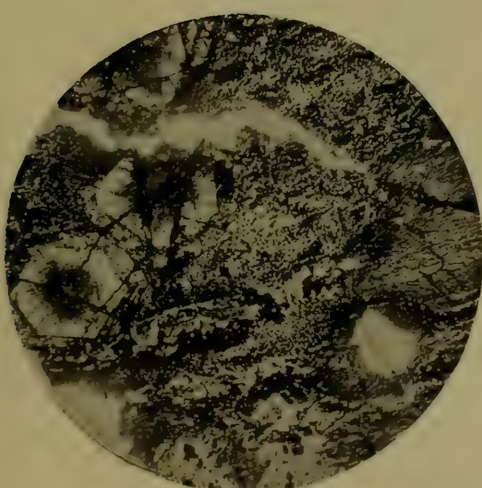
Geological map of portions of the Tweefontein, Vergenoeg, and Zyferfontein districts of the Orange Free State, on the approximate scale of 2·375 inches to the mile, or 1 : 26,680.

1a. × 18

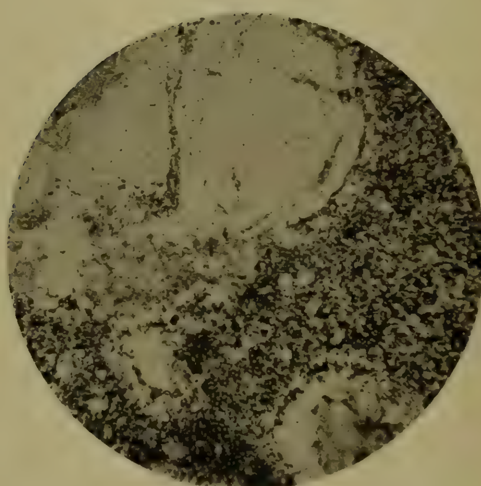
1b. × 18



2. × 8



3. × 18



D. Leighton, Photomicro.

Bemrose, Collo., Derby

Quartz-Soda-Porphyrite, Magnetite-Actinolite-Staurolite-Rock, and Basic Rock from the Orange Free State.

& C. GRAHAM LTD. LITHRS. LONDON. S.E.


GEOLOGICAL MAP OF A PORTION OF THE TWEEFONTEIN VERGENOEG AND ZYFERFONTEIN DISTRICTS OF THE ORANGE FREE STATE.
INDEX
KARROO
LOWER WITWATERSRAND
W5
Quartzite
Slate
Quartzite
Slate
Quartzite
W4
Contorted Band
Slate
W3
Quartzite
W2
Quartzite
Slate
Felspathic Quartzite
W1
Quartzite
Slate
Quartzite
INTRUSIVE IGNEOUS
Granite
Diabase
VERGENOEG
TWEEFONTEIN
ZYFERFONTEIN
AMYGDALOID
LINE OF SECTION
Road
Road to Parys
House
SCALE
0
1/2
1
1 1/2
2 MILES
0
100
200
500
1000
2000
3000 YARDS

Discussion.

Dr. F. H. Hatch said that he had the more pleasure in congratulating the Author on a useful piece of geological work, since he had had the advantage of his assistance when investigating the mineral resources of Zululand for the Natal Government. He was also not unacquainted with the ground which formed the subject of this paper, and he could from his own knowledge testify that the difficulty of laying down geological observations, on maps on which only farm-boundaries and no topographical details were given, had been admirably surmounted. Moreover, the results obtained were of the greatest importance to Transvaal geology generally. Hitherto the Vredefort Granite had been considered as one of a series of ancient intrusions in beds of Swaziland age, and older than the Witwatersrand Series. The Author showed that not only was the Vredefort Granite intrusive into the Witwatersrand Beds, but also into diabases which probably were genetically connected with the Ventersdorp Volcanic Series. This would make the granite post-Ventersdorp, and possibly of the same age as the Red Granite of the Boschveldt, which was later than the Pretoria Beds. Since in the Red Granite there had been numerous discoveries of stanniferous deposits, it might prove worth while also to search the Vredefort Granite for tin-ore.

Dr. J. W. Evans thought that the paper showed the value of detailed mapping in deciphering the true structure of a district. Once more a supposed 'fundamental' granite, upon which ancient sediments were believed to rest unconformably, had proved to be intrusive in them. The evidence of overhead stoping was of great interest. It was easy to understand how fragments broken from the roof covering a granite magma would sink through the latter, which would have a very low density—not only on account of its acid character, but also because of the large amount of water and other volatile constituents that it appeared invariably to contain. A basic magma, on the other hand, would have too high a specific gravity to permit as a rule of overhead stoping of this character.

Mr. F. P. Mennell said that, although he had no special knowledge of the particular locality referred to in the paper, it was evidently of great interest. There was a possibility besides that which the Author had pointed out of connexion with the Transvaal 'Red Granite.' The granite-masses of the Cape Province were intrusive in the Malmesbury Slates; and although these were, at one time, supposed to be the bottom of everything, they were now considered as probably equivalent to the Pretoria Beds, so that they really came quite high up, as things went in South Africa. The southern granites might, therefore, be considerably younger than the northern granites, and the Vredefort mass might fall into the former group. The Author did not seem to have given any petrographical account of the rock, and it would be interesting to know whether it was characterized by microcline like the great northern granite-masses, or orthoclase like those of the Cape.

16. *On the* Development *of* *Tragophylloceras loscombi* (*J. Sowerby*). By Leonard Frank Spath, B.Sc., F.G.S. (Read May 27th, 1914.)

[Plates XLVIII–L.]

Contents.

I. Introduction.

As is well known, few localities are so productive of well-preserved Liassic ammonites as the cliffs at Lyme Regis and Charmouth. They have furnished a considerable proportion of the types of Lower Liassic ammonites created nearly a century ago in 'The Mineral Conchology of Great Britain,' and one of these types, fortunately one of those the figures of which were good enough to allow of correct interpretation by later authors, is *Ammonites loscombi* J. Sowerby (1817).[1] During a prolonged investigation of the Liassic succession at Charmouth, Mr. W. D. Lang (1913) has collected abundant fossil material with particular reference to its exact stratigraphical horizon, and I am indebted to him for permission to study the ammonites. In this material, *Tragophylloceras loscombi* is represented by hundreds of specimens (chiefly young), and a study of the ontogeny of that interesting ammonite forms the basis of the present paper. The bearing of certain important facts brought out in this study upon the phylogeny of the genus *Tragophylloceras*, and the speculations on the connexion of the latter with allied lineages,[2] will prove, it is hoped, of general interest.

[1] For full reference see the list of works at the end, § V, pp. 359–60.

[2] The term lineage is here employed to denote a single genetic line or series, that is, generally, a genus: although a genus may comprise several lineages, and even their lateral branches, so long as these lineages are offshoots of the same stock. Of course, it would be best to distinguish by a different name every series recognized by ontogenetic evidence as a distinct lineage. But I have not abandoned the customary use of the term genus for reasons of convenience, since an extraordinarily large number of new lineages would have to be created for, often, only one or two forms.

It will be noted that the term lineage was originally suggested by J. F. Blake (1892) as a substitute for genus, although he uses the term himself for the family Arietidæ as well as for the sequence *Cœloceras-Peltoceras-Aspidoceras*. The term formenreihe, translated by Waagen (1875) himself as 'developmental series,' in its original meaning (1869) included a number of lineages and genera diverging from a radical form, and therefore its connotation was more extensive than either lineage or genus; in other words,

II. Horizon and History.

Sowerby stated that his ammonite came from the 'Blue Lias,' but gave no further details. The type-specimen, which is preserved in the British Museum (Geological Department, No. 33425), shows the bluish limestone-matrix, iridescent pearly layer, and general mode of preservation of the specimen figured by Wright (1880) (B.M. C 2205) and stated to be a

'very characteristic fossil of the "Green Ammonite Bed," Middle Lias near Charmouth';

and further, numerous other specimens examined (Nos. 4–7 of Table II, p. 343 are typical examples of these). There can be no doubt that they come from the 'Lower' and 'Upper Limestones' of Mr. Lang's classification. *Tragophylloceras loscombi* occurs also in the intermediate 'Red Band'; but the fossils of this bed are characterized by their different appearance. Oppel (1856) probably collected his specimens from the 'Lower Limestone,' for he states that *Deroceras davœi* occurred immediately above, which is the case at Charmouth. All the specimens of this rare fossil collected by Mr. Lang (1914, p. 328), at least, came from this horizon: that is, from the 'Red Band' or immediately below. But Oppel erroneously considered *Tr. numismale* (Quenstedt), which occurs in Württemberg in the *Jamesoni* Zone (and apparently considerably below the *davœi* bed) as identical with the later *Tr. loscombi*, an error which caused confusion for nearly forty years, until Pompeckj (1893) separated the two forms. Even he, however, based their separation only on differences of dimensions, umbilicus, and suture, and did not recognize their different geological age.

Numerous small ammonites preserved as internal casts in iron-pyrites are found in the four clays of the Green Ammonite Beds. These will be shown to be the young of *Tr. loscombi*, and from them the ontogeny of this form has been worked out; but they are accompanied by a very few large specimens in a badly crushed condition. The small casts are septate throughout, and in no case was a body-chamber discovered, hence they are not adult specimens of an undescribed form. Also, at a diameter of 25 mm. there was no trace of a crenulation of the periphery that would indicate affinity with *Tr. ibex* (Quenstedt); there is no resemblance to young examples from Gloucestershire, which agree very well with the descriptions of the young of *Tr. ibex* given by A. d'Orbigny (1842; as *A. boblayi*) and by Pompeckj (1893, p. 22).

In the Belemnite-Stone, which lies immediately below the base of

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it represented a family. Later authors have used the term formenreihe for genera, as well as for only single genetic lines: that is, lineages.

It is clear that ontogenetic evidence alone will enable us to trace the interconnexion of these developmental series, and thus approximate to a natural (as distinct from the present more or less morphological) classification of ammonites.

the Green Ammonite Beds, larger specimens again occur, closely resembling *Tr. loscombi* in dimensions and suture-line, but differing in a slightly crenulated periphery (No. 13 in Table II). Now *Tr. paucicostatum*, which Pompeckj (1893, p. 11) records from the *Ibex* Zone, is very similar, and differs but slightly in suture-line and in having a larger umbilicus. Woodward & Ussher (1911) record *Liparoceras bechei* (Sow.)[1] from the Belemnite-Stone, and other specimens of true Lipocerata have been found at this horizon; the evidence as to the age of the beds afforded by the forms of *Tragophylloceras* is unsatisfactory, and the boundary between the *Ibex* and the *Davœi* Zones cannot yet be definitely fixed. Crenulation of the venter, as we shall see later, is anagenetic in the forms of the *Ibex* Zone as well as in the high-zonal forms from Golden Cap and Seatown (Nos. 9 & 10 in Table II, p. 343), and even in body-chamber fragments from the zone of *Amaltheus margaritatus*. The horizon of these beds will be reconsidered when their ægoceratid ammonites, which are of greater zonal value, are dealt with.

The points, then, to be noted are, first, that *Tragophylloceras loscombi* has its greatest development at the horizon of *Deroceras davœi*, although it persists into *margaritatus* times. Secondly, that the small, immature ammonites are mostly higher than the *Ibex* zone, and at any rate not associated with *Acanthopleuroceras*, which occurs immediately below the base of the Green Ammonite Beds. It should be added that, unfortunately, the mode of preservation of the larger specimens of *Tr. loscombi* prevents a direct comparison of their inner whorls with the small casts occurring in such abundance in the clays.

Sowerby's description and figures are reasonably good, though he gave no section, and the thickness of the shell could be gathered merely from his remark 'Thickness being only one-third the length' (of the aperture); but this is not quite correct. In fig. 1 of Pl. XLIX the sectional view of Sowerby's type-specimen is reproduced, and it will be seen that it differs from the section of A. d'Orbigny's ammonite (1842, pl. lxxv, fig. 2). Pompeckj (1893, p. 13) thought that the latter was, perhaps, not the same as Sowerby's. In the British Museum collection, however, there is a specimen (No. 37181, Coll. Tesson) from Vieux Port (Calvados), which is a topotype of some of A. d'Orbigny's specimens, and differs in no particular from the English type. Furthermore, Prof. Paul Lemoine kindly informed me that A. d'Orbigny's type-specimens preserved in the Muséum d'Histoire Naturelle (Collection de Paléontologie) are in a mediocre state of preservation, and somewhat flattened and deformed artificially. Since d'Orbigny did not give the locality of his figured specimen, it is of course impossible now to identify it with certainty; but the specimen that seems to

[1] I was kindly permitted to examine this specimen in the collection of the Geological Survey, but it cannot be identified closer than as *Liparoceras* sp. It cannot be *A. bechei* (Sow.), which occupies a higher horizon.

come nearest the figure is one from Lyme Regis. There is thus enough evidence to show that the drawing of the French ammonite is incorrect.

The shell figured by Wright (1880) is also represented with a wrong apertural view, which led Mr. Buckman (1910) to remark that this form was much thicker than Sowerby's. In fact, Wright's type is crushed and half-embedded in matrix, and there is no reason to believe that its section originally differed in the least from that of Sowerby's type. Descriptions of *Tragophylloceras loscombi* have also been given (without figures) by Tate & Blake (1876) and Dumortier (1869); but, since most of the earlier authors neglect dimensions, and since Pompeckj (who for the first time dealt more fully with these forms, especially the Swabian representatives of the genus *Tragophylloceras*) had insufficient material, it will be necessary to redescribe *Tr. loscombi* in detail after its ontogeny has been traced.

It should be added that *Ammonites loscombi* had generally been included in the genus *Phylloceras*. Even Futterer, who established the 'Formenreihe des *Phylloceras loscombi*,' and traced it back to *Monophyllites*, thus clearly characterizing it as a separate lineage, left it in that genus. But in 1900 Hyatt created the new genus *Tragophylloceras* for Quenstedt's *A. heterophyllus numismalis*, the oldest form of the '*loscombi* Formenreihe.' Prinz, in 1906, objected that the genus, based on a mere mention of the type-species, and created without adequate description, could not be accepted. In 1907 Vadasz proposed '*Phyllolobites*' for the 'group of *Phylloceras loscombi*,' and rejected Hyatt's term, not only on account of insufficient definition, but also on account of its being included in the family Phylloceratidæ, whereas Vadasz would assign his '*Phyllolobites*' to the family Amaltheidæ. Since a definition has now been supplied by Mr. Buckman (1912, p. viii), Hyatt's generic name must be adopted for the present lineage; and, as regards the affinity of the genus *Tragophylloceras* with *Amaltheus*, I can only say that, after developing young forms of *Amaltheus* back to the initial chambers, and tracing the evolution of the suture, I agree entirely with Pompeckj (1893, p. 23) and Buckman (1913, 2, p. vii), and reject Vadasz's theory.

III. Ontogeny.

A considerable number of specimens ranging up to 20 mm. in diameter were dissected back to the initial chamber or protoconch, the 'phylembryonic stage' of Dr. Perrin-Smith (1898). This consists of the usual transversely-elongate, barrel-shaped chamber, the short and long axes of which measure 0·4–0·45 and 0·55–0·65 mm. respectively. Figs. 1–3 (Pl. XLVIII) represent in different positions the initial chambers of three specimens collected 10 feet above the Belemnite-Stone (3 feet above the Lower Limestone) on Black Ven. In Branco's nomenclature fig. 3 *a* represents the lateral, and fig. 2 *c* the frontal, aspect; whereas figs. 1 *a* & 2 *a* give the

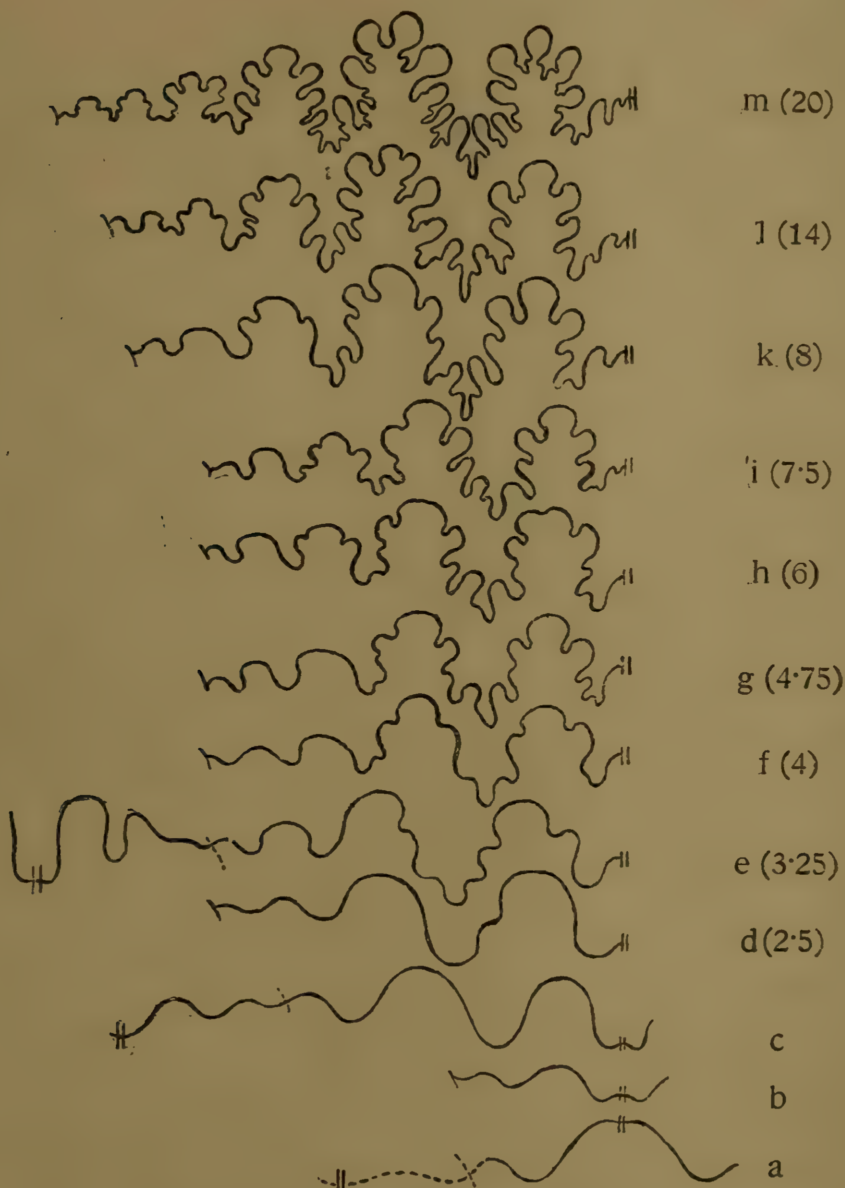
view 'from above.' Figs. 1 *b*, 2 *b*, and 3 *b* could similarly be styled 'aspect from below.' There is very little variation in shape, not only in these three but also in all the other initial chambers examined; this agrees with what Branco says about their constancy in a given species. As that author has pointed out, it is probable that the embryonic shell is represented by only a part of this initial chamber, and the use of the term embryo in Quenstedt's sense for young ammonites up to various diameters is to be deprecated.

The initial chamber contains the commencement of the siphuncle; but no sign was discovered of the structure (prosiphon) observed by Munier-Chalmas in the first chamber of ammonites, which Hyatt compares with the siphuncle in *Endoceras*. The mode of preservation (casts in iron-pyrites, which easily break up into the component chambers on treatment with dilute acid, the interstices being filled with calcite) may be unsuitable for the survival of so delicate a structure; but it must be remembered that neither could Branco find any prosiphon such as that described by Munier-Chalmas, although Hyatt did so in the bulb of *Spirula* (*teste* Blake, 1892, p. 291).

The first septum, separating the protoconch from the succeeding (first actual) chamber, is an oval with a long axis like that of the protoconch, transverse to the plane of coiling (see Pl. XLVIII, fig. 2 *c*). It is pierced ventrally by the large siphuncular tube. The curvature of the first suture-line out of the plane of the oval consists of a large ventral saddle: that is, the ammonite is angustisellate (Pl. XLVIII, fig. 2 *a*). A minute indentation at the summit of this ventral saddle (incipient ventral lobe) was observed in several cases (Pl. XLVIII, fig. 5, and text-fig. 1 *a*). Branco (1879) had noticed this indentation in only a very few ammonites. The protoconch of *Tr. loscombi* differs somewhat in shape from that of *Phylloceras heterophyllum* as figured by Branco (1879, pl. ix, fig. 1), and approaches perhaps more to that of *Monophyllites* [*Lytoceras*] *simonyi* (1879, pl. viii, fig. 5). All these initial chambers are characterized by their comparatively large size, whereas that of *Psiloceras planorbis*, according to Branco (1879, pl. x, fig. 3), is decidedly small. However, as that author has already pointed out, this is an unimportant character, and probably connected with local (environmental) conditions of development.

The second suture already has a median lobe (fig. 5, Pl. XLVIII, and text-fig. 1 *b*); and the development of the following sutures, up to a diameter of about 20 mm. where there are six saddles and lobes (delineated in text-fig. 1, p. 341), will have to be traced in detail later. The section of the shell up to this diameter represents a gradual transition from a depressed to a circular and finally compressed character. A comparison of figs. 4 *a* & 6 of Pl. XLVIII with figs. 2 *b*, 3 *a*, & 4 *b* of Pl. XLIX will show this clearly. The first three figures, taken at the second, seventh, and twentieth sutures respectively, represent specimens from 10 feet above the Belemnite-Stone: that is, 3 feet above the 'Lower Limestone' on Black Ven.

Fig. 1.—*Development of the suture-line of* Tragophylloceras loscombi (*J. Sowerby*).



[*a*, *b*, & *c*, representing the first, second, and seventh sutures, belong to a specimen (No. 1575, Coll. Lang) from 10 feet above the Belemnite-Stone; *d–l* (No. 919, Coll. Lang) come from 14 feet above it; and *m* (No. 1201, Coll. Lang) again from 10 feet above the Belemnite-Stone, all from Black Ven. The numerals indicate the diameters in millimetres.]

Fig. 3 *a*, Pl. XLIX, represents a high-zonal form (35 feet above the Belemnite-Stone: that is, horizon of the 'Upper Limestone' on Stonebarrow Cliff); but, except in the suture, it differs in no respect from the ammonites occurring below. It will be noticed that the whorl-section reaches the circular stage at a diameter of 2 mm., just as it does in *Psiloceras planorbis*; whereas in the Triassic *Pompeckjites layeri* (Hauer) it is reached even earlier. *Lunuloceras lunula* (Zieten), on the other hand, does not become circular in section until a diameter of 4 mm., indicating a long series of evolute, depressed ancestors. These figures also illustrate the transition from the rounded umbilical edge of the widely-umbilicated young shell to the perpendicular wall of the larger specimens, which at a diameter of 6·25 mm. already (fig. 4, Pl. XLIX) resemble in this respect the adult type (fig. 1, Pl. XLIX).

The siphuncle, which is exceedingly wide, pierces the septa first ventrally (fig. 2 *c*, Pl. XLVIII), then subcentrally (fig. 6, Pl. XLVIII), and does not resume its ventral position until near the tenth chamber. The distance between the septa is very constant; there are fourteen septa to the whorl at a diameter of 0·9 mm. (fig. 2 *a*, Pl. XLIX, to second constriction), fourteen at 2·8 mm. (fig. 3 *a*, Pl. XLIX), and fourteen again at 6·25 mm. (fig. 4 *c*, Pl. XLIX).

Table I. (Change of the shape of the whorl coincident with the increase in diameter.)

	Diameter in millimetres.	*Height. Per cent.*	*Thickness. Per cent.*	*Umbilicus. Per cent.*
No. 1 (fig. 7, Pl. L)	1·2	35	44	37
2 (fig. 8)	2·8	43	40	33
2 *a* (fig. 9)	6·25	55	35	20
3	5	55	37	22
4	6·5	54	31	22
5	7	54	30	21
6	7·5	54	29	19
7	8	53	28	22
8	8	53	31	20
9	11	52	27	20
10	11	52	27	16
11	11·5	51	26	17
12	12	50	27	16
13	13	54	31	15
14	13·4	49	30	21
15	14·25	54	27	16
16	15	53	26	15
17	17	50	24	21
18	18	51	25	16
19	19	52	23	16
20	20	50	23	16
21	25	53	26	14
22	38·5	53	24	13

The change of whorl-shape with increase of diameter is illustrated in Table I (p. 342). The specimens came partly from 10 feet above the Belemnite-Stone on Black Ven (Nos. 1, 3, 4, 6, 11, & 20), and partly from the horizon of the Upper Limestone (Nos. 2, 5, 7, 9, & 19); the remaining specimens were not collected in place, but they also came, of course, from the Green Ammonite Beds of Black Ven and Stonebarrow. With the exception of the three ornamented specimens (13, 14, & 17), of which I shall have to speak again later, there is a very regular decrease in thickness and size of the umbilicus; and, as a comparison of Table I with the dimensions of adult specimens given in Table II (below) will demonstrate, the characters of the typical form already are present at a diameter of 25 mm., whereas specimens measuring between 10 and 20 mm. still have a slightly larger umbilicus and are a little thicker.

With regard to Table II, which deals with adult forms, it is a matter for regret that, on account of the unsatisfactory mode of preservation, no large specimen could be developed back to the protoconch. But, as a comparison of the dimensions, and especially the development of the suture-line, will show, there can be no doubt concerning the connexion of the small pyritized casts with the large calcareous shells so commonly found as body-chambers only.

Table II.

	Diameter in millimetres.	*Height. Per cent.*	*Thickness. Per cent.*	*Umbilicus. Per cent.*
1. Sowerby's type	78	54	23	13
2. Wright's figs. 4 & 5, pl. xl ...	148	53	?23	14
3. Pompeckj's specimen 1	65	52	23	14
4. Specimen 919 *a* (Coll. Lang)...	94	52	26	14
5. Specimen 621 (Coll. Lang) ...	98	53	25	13
6. Spec. 1390 (Coll. F. H. Butler).	78	54	23	13
7. B.M. 90 (Coll. De la Beche) ...	48	52	?25	?12
8. B.M. C 3719 (Coll. Beckles) ...	77	?55	—	?11
9. B.M. C 12609 (Coll. H. S. Romer). Seatown.	109	52	24	12
10. B.M. C 7301 (Coll. Slatter). Golden Cap.	95	53	26	13
11. B.M. C 6731 (Coll. Slatter). Little Wolford, Warwickshire.	53	?54	?23	?12
12. B.M. C 12633 (Coll. Watson). Napton Hill.	66	55	24	11
13. From Belemnite-Stone (Coll. Lang).	53	52	22	14
14. D'Orbigny's specimen (text)...	90	55	25	10
14 *a*. do. (fig.)	92	54	24	13
15. B.M. 37181 (Coll. Tesson). Vieux Port, Calvados.	69	55	25	13
16. Pompeckj's specimen 3. Sables, near Bayeux.	67	55	26	12

Specimens 1–7 & 13 come from the Lyme Regis district. The locality of No. 8 is unknown. No. 11 represents a slightly crenulated, probably low-zonal variety.

The specimens are still perfectly smooth at a diameter of 5 mm., though, after this diameter is reached, some of the casts begin to show shallow, sigmoidal depressions on the sides, corresponding to indefinite pleats on the original shell.

The constrictions of the young shells, however, are an important feature. They appear sometimes as soon as the fifth, more often at about the seventh to tenth septum, and persist fairly regularly on the innermost two and a half or three whorls. Those specimens that show twelve constrictions up to a diameter of 3·5 mm. belong exclusively to the lower horizons (7 and 10 feet above the Belemnite-Stone on Black Ven); whereas in the upper beds (35 feet above the Belemnite-Stone on Stonebarrow Cliff=horizon of the Upper Limestone), seven or eight constrictions persisting to about the diameter of 2·5 or 2·75 mm. were observed. Since, however, there is a good deal of variation in the number of constrictions, even in the specimens from the lower beds, and since the shells of undoubted Upper Limestone horizon are comparatively few, it is uncertain whether any phylogenetic significance attaches to this difference.

Figs. 2 *a* & 3 *a* in Pl. XLIX show the course of the constrictions. They are slightly inclined forward, except, perhaps, the first one, and follow one another at intervals of, generally, a fifth to a sixth of a whorl.

The smallest specimens that have the shell preserved (9 and 15 mm. in diameter respectively) show the costation of the adult form apparently a little more pronounced. This, however, applies chiefly to the middle of the side, where also the previously-mentioned sigmoidal grooves on casts exceeding 5 mm. in diameter appear. There is no tendency to ornamentation manifest near the periphery. The curve described by the radii is shown in figs. 6–14 of Pl. L, together with the course of the striation in typical forms of *Monophyllites*, *Mojsvarites*, *Psiloceras*, *Euphyllites* and *Rhacophyllites*.[1] Several body-chamber fragments from higher horizons, up to and including the lower part of the zone of *Amaltheus margaritatus*, show a striate ornament with very distinct fasciculation; whereas the usual specimens, like Sowerby's type, show a more or less irregular, lineate ornament. Occasionally, very fine striation is superimposed upon the lineation or costation; but, in typical forms, the costæ do not blend into thickened bundles of radii near the inner part of the side. No definite order in the variation of ornament and in the occasional sudden appearance of scales on the periphery could be demonstrated; neither could it be determined as of zonal significance.

Three small specimens (13, 14, & 17 of Table I) and four other fragments, unfortunately not found in place, deserve special mention, on account of differences in ornament. Two of the fragments and specimen 17 are distinguished by close sigmoidal

[1] Only one specimen (a body-chamber fragment from Watford, near Rugby. B.M. 20138) was found to differ in the curve of the radial line, having the rostration near the periphery unusually pronounced.

costation, which is more pronounced than usual. One other fragment and a small cast show a distant sigmoidal costation, which, together with the sharpened and very slightly notched periphery, recalls young forms of *Tragophylloceras ibex.* Specimen No. 13 and a small fragment are characterized by a very unusual straight costation, thickening towards the slightly-sharpened periphery.

A complete mouth-border does not seem yet to have been discovered, although body-chambers of *Tr. loscombi* are fairly common. This might be explained by the fragility of the shell. In the case of *Tr. ibex*, however, a complete mouth-border is by no means rare, although Pompeckj (1893, p. 22) says that it is unknown. The longest body-chambers of *Tr. loscombi* that were examined measured nearly three-quarters of a whorl. There also is no evidence as to the presence of an aptychus.

The development of the suture-line will now be traced in detail.

The ventral portion of the first suture has a large external saddle, two lateral lobes, and two small lateral saddles. The external saddle resembles that of the first suture of *Monophyllites simonyi*, as also of *Phylloceras heterophyllum* (Branco, 1879, pl. viii, fig. v [*Lytoceras simonyi*] and pl. ix, fig. 1), and is less triangular than that of *Psiloceras planorbis* [*Ægoceras planorbis*] (pl. x, fig. 3). The lateral saddles are intermediate in size between those of the two first-mentioned forms. The dorsal portion of the first suture consists of a median shallow lobe, two saddles, and two indistinct lateral lobes (see text-fig. 1 *a*, p. 341).

The second suture belongs to what Branco terms the more complicated (but far more usual) type, and presents, besides the external lobe, two external saddles, two lateral lobes, two lateral saddles, and already two indistinct second lateral lobes. The second suture generally meets the first one at or near the umbilicus. It will be noticed that the ventral lobe is already divided by a median saddle; whereas in *Phylloceras heterophyllum* this division does not occur until the third suture, and in *Monophyllites simonyi* not until the fourth or fifth.[1]

The third suture closely resembles the second; but, in the subsequent sutures a second lateral saddle is developed at the umbilical end, and in the seventh suture both the ventral and the lateral lobes have become deep and the saddles very pronounced. The internal (dorsal) lobe has also deepened, and a second saddle appeared at the umbilical end.

The undivided suture of the 'goniatite-stage' persists, as in all ammonites, to a diameter of about 2·5 mm. The 'ammonite-stage' is already indicated at that diameter by the presence of a notch on the internal half of the external saddle, and the following suture (text-fig. 1 *e*, p. 341), taken at a diameter of 3·25 mm., shows

[1] Branco is not quite sure about this (1879, p. 32).

not only the external saddle and first lateral lobe, but also the first lateral saddle already dividing. A further saddle has appeared at the umbilical end, and the internal suture now consists of a very deep and bifid dorsal lobe and two long and narrow saddles.

Between the diameters of 4 and 8 mm. (text-figs. 1 *f*–1 *k*, p. 341) the suture consists of five saddles; and especially noteworthy is the monophyllic character of the large terminal leaflets. The monophyllic ending of the external saddle is characteristic, even in the adult suture; and the terminal leaflet is larger than the two leaflets below up to a diameter of 14 mm. At that diameter the first lateral saddle assumes the peculiar, subdiphyllic character which it shows throughout the adult stage. The internal lower leaflet increases in size, and grows forwards until it nearly rivals in height the terminal leaflet, and, with it, forms the characteristic claw-like ending of the first lateral saddle, which is as distinct in *Tragophylloceras ibex* and in *Tr. numismale*, as it is in *Tr. loscombi*. The four auxiliary lobes found in the adult suture are developed already at a diameter of 20 mm. They decrease regularly towards the umbilicus, and keep just above the normal: that is, the line connecting the deepest part of the ventral lobe with the centre of the shell. Throughout the development the first lateral saddle is higher than the external saddle, and the first lateral lobe is deeper than the ventral lobe from a very early stage.

With regard to variation in suture-line, it should be mentioned that a specimen (figs. 3 & 4, Pl. XLIX) from a higher zone already shows a stage corresponding to text-fig. 1 *d* (p. 341) at a diameter of 1·8 mm., and the stage 1 *f* (reached by the typical forms only at the diameter of 4 mm.) at 3 mm. On the other hand, a larger specimen from the horizon of the Upper Limestone shows, at the diameter of 17 mm., a suture which is essentially that of text-fig. 1 *m* (p. 341).

Before the allied forms are considered, the description of *Tragophylloceras loscombi* given by Sowerby ought to be extended, in consideration of the developmental evidence. A formal description might run thus:—

Shell compressed, subextremiperplatygyral (height = 52 to 55 per cent. of the diameter), with slightly convex sides that merge without edge into a rounded periphery. The sectional view thus shows an elongated oval; the greatest thickness occurs at one-third of the height (23 to 26 per cent. of the diameter, therefore subleptogyral); the umbilicus measures 10 to 14 per cent. of the diameter (angustumbilicate), and has a vertical wall with a rounded edge; the involution amounts to five-sixths of the height. The inner whorls are first depressed, with no inclusion, and at a diameter of about 2 mm., circular with slight inclusion and an open umbilicus of approximately 35 per cent. Between the diameters of 5 and 20 mm. the shells are but slightly thicker and more widely umbilicated than the adult shells: at a diameter of 25 mm., however, the characters of the latter are typically developed.

The innermost two and a half to three whorls bear from five to twelve constrictions persisting not later than the diameter of 3·5 mm.

The shell is ornamented with delicate costæ, of which there are forty on the last half-whorl of the type-specimen. They describe a sigmoidal curve, having a convexity forward at the inner third of the side and crossing the periphery in a second convex curve forward. Occasionally in older shells (on the body-chamber) the radii tend to thicken along the rounded ventral region to form faint scales. Length of body-chamber = probably nearly three-quarters of a whorl; mouth-border and aptychus unknown.

The suture-line normally presents four auxiliary lobes. The external saddle is lower than the first lateral saddle; the median saddle of the ventral lobe is comparatively high, and the first lateral lobe is deep. The external saddle is monophyllic throughout the development, as are all the other saddles except the first lateral saddle, which assumes a subdiphyllic appearance in the adult. The terminal leaflets of the three principal saddles are lanceolate, spoon-shaped in the adult; the remainder, like the young saddle-endings, truly phylloid.

Allied Species.

Mr. Buckman (1910) has redescribed and figured Simpson's *Ammonites ambiguus*, which came from Robin Hood's Bay, presumably from the *Valdani* Zone.[1] This ammonite differs very little from *Tragophylloceras loscombi*.[2] Its umbilicus is 15 per cent. of the diameter, instead of the usual 10 to 14 per cent.; and its thickness is probably 29, not 23 to 26 per cent. Its whorl-section may also be a little more trigonal in shape. Unless found to differ in suture-line, however, this form would hardly be regarded as more than a variety of (*mutatio ascendens ad*) *Tr. loscombi*.[3]

The other ammonites included in the genus *Tragophylloceras* can be divided into two groups: namely, that of *Tr. numismale* and that of *Tr. ibex*. The former includes, besides the trigonal-whorled, striate *Tr. numismale* (Quenstedt), its crenulate, compressed development *Tr. typicum* S. S. Buckman; the stout-whorled *Tr. elteni* (Pompeckj), and the densicostate *Tr. intracrustatum* (Quenstedt); the similar but more crenulate *Tr. wechsleri* (Oppel), and the sparsicostate *Tr. paucicostatum* (Pomp.). A number of forms such as *Tragophylloceras* n. sp. (= *A. ibex-heterophyllus* Quenst. 1885); Futterer's (1891) fig. 6 *a* of pl. viii; and Wright's (1880) figs. 1–3 of pl. xxxix, are transitional to the typical,

[1] At first, also with a query, recorded from the *Capricornus* Zone.

[2] Tate & Blake (1876, p. 296) considered it to be a synonym of *Tr. loscombi* (J. Sowerby).

[3] *Ammonites nanus* Simpson and *A. huntoni* Simpson are, according to information kindly forwarded by Mr. Buckman, probably young forms of *Tragophylloceras*. Similarly, *A. robinsoni* Simpson may belong here, to judge by two specimens in the British Museum (N. H. 37987) bearing Bean's original label.

coarsely-ornamented *Tragophylloceras ibex.* With the exception of *Tr. numismale* and *Tr. elteni,* which are quoted by Pompeckj from the *Jamesoni* Zone, all the forms mentioned above appear to belong to the *Ibex* Zone. '*Phylloceras*' *dolosum* Meneghini (1881), included by Pompeckj in the present group, is characterized by diphyllic saddles which, together with its occurrence in the Mediterranean province, point to a connexion with *Rhacophyllites.* '*Amaltheus* (*Sphenodiscus*)' *sinister* Canavari (1882), which is compared by its author with *Tr. loscombi*, similarly has a *Rhacophyllites* suture.[1]

Before any opinion on the interconnexion of these forms can be expressed, the ontogenetic evidence regarding *Tr. ibex* and *Tr. numismale* must be examined. The latter, according to Pompeckj (1893, p. 16), has constrictions up to the diameter of about 20 mm., a section which is as high as it is wide still at a diameter of 4 mm.; whereas at 7 mm. the relation of height to thickness is as 31 : 25, instead of 31 : 17 as in *Tr. loscombi.* On the other hand, the suture of *Tr. numismale* shows a beginning of the division of the saddles at the diameter of 4 mm. only, whereas this stage is reached much earlier in *Tr. loscombi.* The median saddle in the ventral lobe of *Tr. numismale* also is much simpler than it is in *Tr. loscombi.* From the study of the ontogeny of *Tr. loscombi* it is clear that such a stouter-whorled form with constrictions persisting longer, and with a simpler suture-line,[2] was in the direct line of ancestry of Sowerby's ammonite. Now Pompeckj (1893, p. 18) considered the developmental series *numismale-wechsleri-ibex* more probable than the two developments put forward by Futterer, the latter tending to develop densicostate and sparsicostate forms respectively. Neither author, however, seems to have been aware of the existence of a striate *Tragophylloceras* fauna in post-*ibex* times.

As regards *Tr. ibex*, constrictions persist, according to Pompeckj, up to the diameter of 5 mm., and the whorls soon become very thin with an almost sharpened periphery. A comparison of text-fig. 1 *m* (p. 341), showing the suture of *Tr. loscombi* at the diameter of 20 mm., with that of *Tr. ibex* at 25 mm. (Pompeckj, 1893, p. 23, text-fig. 3) will also testify to the simpler development in the latter. It is true that fig. 1 *b* of Pompeckj (1893, p. 23), taken at about the diameter of the accompanying fig. 1 *h* (p. 341), shows a much greater advance; but, on the other hand, from the evidence of young specimens of *Tragophylloceras ibex* from Gloucestershire

[1] In 1888, Canavari ('Contribuzione alla Fauna del Lias inferiore di Spezia' Mem. R. Com. Geol. Ital. vol. iii, pt. 2, p. 34) assigned this form to the genus *Oxynoticeras*!

[2] Pompeckj bases his distinction between *Tr. loscombi* and *Tr. numismale* partly on the presence of four auxiliary lobes only in the former, but six in the latter; in view of the developmental evidence this need, however, cause no uneasiness. A comparison of the section of Sowerby's type (fig. 1, Pl. XLIX) with Quenstedt's (1885) fig. 9 on pl. xxxvii will show the difference in the umbilical region between the two forms which might easily account for the varying number of auxiliary elements in the sutures.

in my own collection, it appears that the stage shown in fig. 1 *k* (p. 341), reached by *Tr. loscombi* at the diameter of 8 mm., is not attained by *Tr. ibex* until between 10 and 18 mm. Constrictions and suture, therefore, point, here also, to a more primitive condition than in *Tr. loscombi.* The adult *ibex* suture is characterized by slender and long terminal leaflets on the saddles, and by the raising of the auxiliaries above the normal, both of which characters were observed in the slightly-crenulated form from the Belemnite Stone (fig. 2 *e*), and in another, similar, specimen, not found in place,[1] which shows these slender leaflets already present at a diameter of 15 mm.

Whether, now, we accept Pompeckj's developmental series *numismale-wechsleri-ibex*, or the more probable lineages put forward by Futterer (namely, *numismale-wechsleri* on the one hand, and *numismale-ibex* on the other), it seems that none of them leads to *Tr. loscombi.* In the latter form, if the ornament tends at all to thicken on the periphery, it does so on body-chambers only, and on these at various horizons up to *margaritatus.* The section is uniformly oval between 5 and 20 mm., at which stage in the earlier *Tr. ibex* it is at first high and sharpened peripherally, and then rectangular; finally, the suture-line of *Tr. loscombi*, still at a diameter of 14 mm., shows a large terminal leaflet of the external saddle with two smaller ones below. We must, therefore, look to a *numismale*-like form for the ancestor of *Tr. loscombi*, and not to the strongly ornamented ammonites of the *Ibex* Zone.[2]

With regard to the curious distribution of the forms belonging to the genus *Tragophylloceras* in time and space, it may be suggested that the original, probably Mediterranean, ancestor (whose affinities with various Lower Liassic and Triassic families I shall attempt to trace in the following pages), after migrating into the Swabian Carixian Sea, did not thrive[3] until it took on marked ornamentation, when it spread as far north and west as England and Normandy. The normal, compressed and involute development (*Tragophylloceras loscombi*) followed the migration,

[1] From the preservation and general appearance of this specimen, as well as from the circumstances in which it was collected, Mr. Lang thinks it likely that it came from a foot or so below the Belemnite-Stone, where he found *Acanthopleuroceras ellipticum* (Sow.).

[2] It is interesting to note here that a body-chamber fragment of a specimen of *Tragophylloceras ibex* measuring about 130 mm. in diameter, from Hewlett's brickyard, near Cheltenham (B.M. C 8876), has the lineate ornament of *Tr. loscombi* on the last four-fifths of its half-whorl and is only distinguished by a tabulate periphery and a wide umbilicus. At the posterior end of the body-chamber the typical *ibex* periphery can still, however, be seen; the last suture only is preserved, but unfortunately worn down and therefore not traceable.

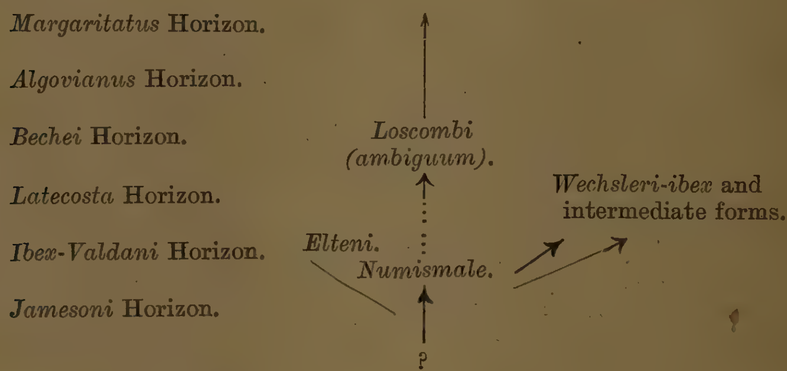
On the evidence of this specimen one might be tempted to consider the later, involute *Tr. loscombi* as a descendant of *Tr. ibex*, the omission of the costate-crenulate stages being explained by saltative palingenesis. It must be remembered, however, that the suture-line in that case would presumably be of a different type in the later form. But the specimen can be regarded as proof of the close relationship, and more or less parallel development, of the *ibex*- and *loscombi*-branches in the genus *Tragophylloceras.*

[3] *Tragophylloceras numismale* is a rare fossil.

but did not become a conspicuous element of the fauna until the ornamented forms had died out.

The latter seem to have displaced the unornamented forms altogether in the southern regions; but, even in England and in France, the group became extinct in *margaritatus* times. The exceptional character of the extreme ornamentation, such as occurs in *Tr. ibex* in the persistently smooth stock of the Phylloceratidæ, may account for the rapid and earlier extinction of the sculptured forms.

The interrelations of the various forms belonging to the genus *Tragophylloceras* might, then, be graphically represented as follows:—



IV. Phylogeny.

Futterer, who established the formenreihe of *Phylloceras loscombi*, had already traced *Tragophylloceras* back to *Monophyllites*, particularly to the group of *M. sphærophyllus.* He based his arguments chiefly on the external characters of the shell, considered the ornament a modified monophyllitic one, and dealt with the (adult) sutures which, in his opinion, showed a gradual transition, especially in the development of a trifid first lateral lobe from the original bifid lobe. The immediate attachment of the Carixian genus to Triassic forms, without consideration of the allied genera that existed in the enormous time-interval, was, however, scarcely convincing. Pompeckj doubted the correctness of Futterer's theory, but expressed no opinion himself.

The latest forms of *Monophyllites* mentioned by Futterer, and therefore the more or less direct ancestors of the lineage, were *Monophyllites aonis* Mojs., and *M. simonyi* Hauer. Now, Futterer left *Ammonites loscombi* in the genus *Phylloceras*, and, if *Phylloceras* be the descendant of *Discophyllites* (as is generally supposed, and as seems to me probable), the genus *Tragophylloceras* is at once removed from the Jurassic Phylloceratidæ; for *Discophyllites* is a branch of the original *Monophyllites* root-stock which is distinguished already at the horizon of the above-mentioned *M. aonis* and *M. simonyi* by bifid saddle-endings.

One of the important features demonstrated in the development of the suture-line of *Tragophylloceras loscombi* was the persistence, up to a diameter of about 14 mm., of a large terminal leaflet on the external saddle, followed by two smaller ones below. According to Pompeckj (1895), this arrangement, which is typical of *Mojsvarites clio* (Mojs.) and *M. planorboides* (Gümbel), occurs, if in a different manner, in *Phylloceras heterophyllum*, but is less distinct in *Tragophylloceras ibex*. Now, Branco's figure (1879, pl. ix, fig. 1 *q*) shows that the suture of *Phylloceras heterophyllum* at 3·25 mm., although very similar, is slightly more advanced than that of *Tr. loscombi* at the same diameter (see fig. 1 *e*, p. 341); both are foreshadowed in the suture of *Monophyllites simonyi* at 3 mm. (*op. cit.* pl. viii, fig. *Vm*), but there is no resemblance whatever to the development of the *Megaphyllites* suture, as Pompeckj considers. In fact, the Triassic *Megaphyllites insectum* Mojs. shows already at the diameter of 2·5 mm. the second lateral lobe as complicated as the first one; whereas, in the Upper Liassic *Phylloceras heterophyllum*, it is perfectly entire up to the diameter of 3·25 mm. The suture of *Ph. heterophyllum* shows a diphyllic external saddle and first lateral saddle already at 7 mm., whereas, as we have seen, at twice that diameter the external saddle of *Tragophylloceras loscombi* has still a large terminal leaflet; and although in *Tr. ibex*, as Pompeckj remarks, this character is less distinct, it is certainly shown on specimens exceeding 8 mm. in diameter.

Moreover, Pompeckj says that in *Psiloceras*[1] there is never developed on the external saddle a large upper leaflet followed by two small ones below, such as in *Mojsvarites*. The development of the suture-line of a specimen of *Psiloceras* aff. *erugatum* (Bean-Phillips) from Robin Hood's Bay, illustrated in fig. 4 of Pl. L, shows that this is not the case. At a diameter of 25 mm. the central terminal leaflet is still the largest, and the suture at 7 mm. diameter will show that the external saddle does not by any means develop three equal leaflets straight from an undivided condition. But this *Psiloceras* suture at the diameter of 7 mm. is almost exactly like that of the accompanying fig. 1 *f* (p. 341) of *Tragophylloceras loscombi* at the diameter of 4 mm.: that is, in a post-constricted stage.[2]

The suture may, indeed, be said to remain in the '*Psiloceras*'-stage up to a diameter of 8 mm. Now, *Psiloceras* is not the

[1] One form generally included in the genus *Psiloceras* occupies really quite a distinct position. This is *A. hagenowi* Dunker, for which the new genus *Psilophyllites* [type: *P. hagenowi* (Dunker), 'Palæontographica' vol. i, 1847, pl. xiii, fig. 22] is now proposed. Dunker's fig. 22 *c* is badly drawn: see Quenstedt (1883) p. 21. His fig. 2 of pl. xvii ought to receive a new name. Until it is shown by ontogenetic evidence that the pseudoceratitic suture of that form is derived by reduction from a psiloceratid one, *Psilophyllites* cannot even be included in the Psiloceratidæ, as a comparison with the development illustrated in fig. 4 of Pl. L will show.

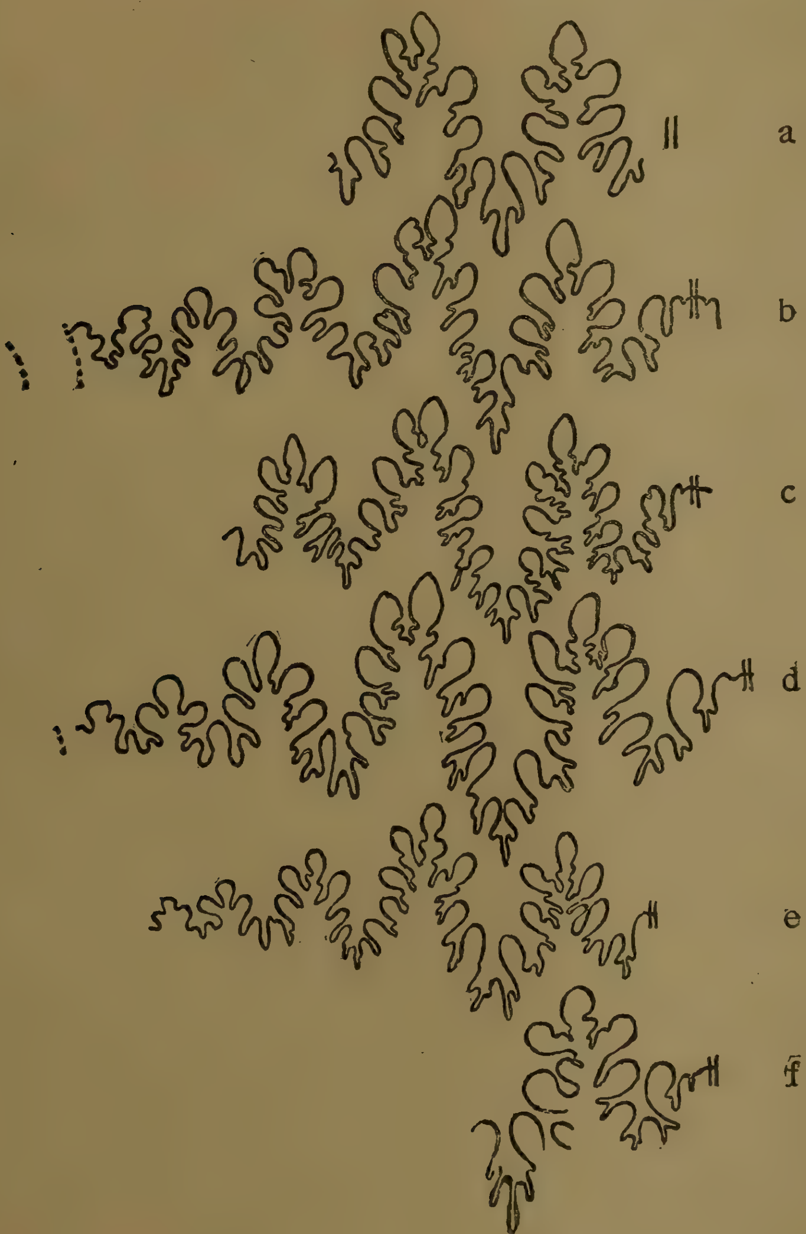
[2] Asymmetry of the suture-line, as characteristic of Psiloceratidæ, was noticed by Pompeckj in a specimen of *Tr. loscombi* from Sables, near Bayeux; but I have not observed it myself in any specimens.

descendant of *Mojsvarites clio*, as Mojsisovics had stated (1893), nor of *M. planorboides*, as Prof. Haug (1908) seems to think; for this genus had attained already a fairly involute condition in the Rhætic, whereas *Psiloceras* (and especially *Parapsiloceras*, which resembles so closely the primitive *Pleuracanthites polycycloides* Wähn.) is still latumbilicate. It is neither a derivative of the diphyllic *Discophyllites* nor of *Phylloceras*, as Pompeckj (1895, p. 40) thinks; but comes from a branch of the original *Monophyllites* root-stock that may have given rise to *Mojsvarites* as well, although it persisted itself in a less advanced condition through Rhætic times, having possibly not only dependent auxiliaries, but also the ornament of the inner whorls of certain forms of *Monophyllites*. Dr. Perrin-Smith (1913) thinks it improbable that *Psiloceras* can be derived from Phylloceratidæ, and states that the resemblance to *Monophyllites* probably is only a convergence-phenomenon. He considers it 'just as likely' that *Psiloceras* is a degenerate series reversionary towards the ancestral radical; but these are mere conjectures. Mr. Buckman, however, has stated as recently as 1912 (*op. cit.* p. vii) that *Psiloceras* is a 'degenerate, (smooth) derivative of a *Caloceras* stock'; but this cannot be admitted in view of the phylloid suture-line. The development of the suture-line shows that that of the later *Caloceras* results normally from that of the earlier *Psiloceras*, as a further modification of the original *Mojsvarites*-like suture. The similarity of the suture-development to that of *Tragophylloceras loscombi* and, less so, to the suture-development of *Phylloceras heterophyllum*, shows that the ancestor of *Psiloceras* must be looked for in the Monophyllitidæ.

The absence of a suspensive lobe (dependent auxiliaries) in forms of the latter family is, in my opinion, not of great importance. Wähner (1886) has already pointed out that it is neither always present in *Psiloceras*, nor always absent in '*Arietites*.' Its significance is doubtful; for it is found in evolute and in involute shells, in ornamented and in smooth forms, in ammonites with few septa as in those with crowded sutures. Some smooth catagenetic oxycones show a strong forward inclination of the auxiliaries, others have dependent inner lobes. On the other hand, *Wæhneroceras*, admittedly a costate *Psiloceras* development, shows the dependent inner lobes; whereas the even more anagenetic (in costation) '*Psiloceras*' *capra-ibex* Pompeckj, from the *Bucklandi* Zone, has a strong forward inclination of the auxiliaries.[1] Thus, in view of the evidence of the phylloid suture, we are not justified in laying

[1] It may not be out of place to mention here that, although some Arietoids seem to be developments of *Caloceras* and *Alsatites*, yet others show ontogenetic characters which do not suggest a derivation from Psiloceratidæ. For example, *Vermiceras spiratissimum* (Quenstedt) has not only a persistently low ventral lobe, but the external saddle is still larger than the first lateral saddle at a diameter of 8 mm.; and, at a diameter of 4 mm., the suture is at least as simple as it is in the Triassic *Monophyllites simonyi* and in *Psiloceras* aff. *erugatum* at 3 and 2·25 mm. respectively.

Fig. 2.—*Sutures of adult specimens of* Tragophylloceras loscombi (*J. Sowerby*). *All the figures are enlarged.*



[*a* = No. 1 of Table II, p. 343; *b* = No. 7 of Table II; *c* = No. 6 of Table II. *d* is from specimen No. 471 (Coll. F. H. Butler): diameter = 43 mm.; umbilicus = 17 per cent.; slightly crenulated, sharp periphery. Probably a low-zonal form comparable with the next one and No. 11 of Table II; its history is unknown. *e* = No. 13 of Table II, and *f* = No. 15 of the same Table.]

stress on the presence of dependent auxiliaries in some psiloceratés, nor in relying on the costation. *Psiloceras* cannot, however, yet be attached to any particular form of the Monophyllitidæ.

But if, on the evidence of the suture-development, we favour the recognition of an early-neanic *Monophyllites* stage [1] and a late-neanic *Psiloceras* stage, we must remember that the evolute and rounded-whorled *Tragophylloceras* ancestor was constricted at a comparatively late date, if we are to argue phylogenetically from the persistence of the constrictions in *Tr. numismale* up to a diameter of about 20 mm. Constrictions occur in a number of genera belonging to the Phylloceratidæ and Lytoceratidæ of the Alpine-Mediterranean Lower Lias, but unfortunately the ontogeny of these forms is unknown. Involute forms are referred to '*Phylloceras*' and most arbitrarily distributed among the groups of *Ph. heterophyllum*, *Ph. capitanei*, and *Ph. partschi*. *Rhacophyllites* is distinguished chiefly by evolute whorls (obviously a most unsatisfactory character) with a correspondingly smaller number of auxiliaries, but has, like *Phylloceras*, typically diphyllic saddles. Fig. 3, Pl. L, shows the development of the suture of *Rhacophyllites stella* (Sow.) from a diameter of 4 mm. The monophyllic second lateral saddle may point to the derivation (by way of *Discophyllites*) from the Monophyllitidæ. The shape of the conch of *Rhacophyllites stella* at diameters of 4 and 6 mm. respectively (Pl. L, figs. 1 & 2) is the morphic equivalent of the hypothetical *Tragophylloceras* ancestor; and, if the evidence of the suture-line were not so decisively against it, one might be tempted to accept Geyer's opinion of the relationship of these two genera.

The undue importance given to whorl-shape in these phyllocerates is responsible for the extraordinary confusion which prevails in the grouping of the 120 forms of the Lower and Middle Lias. The forms referred to *Geyeroceras* [2] and to the group of *Phylloceras persanense* Herbich, show the variability in section. Some of these forms are, by their sutures, allied to *Phylloceras*, while others are clearly rhacophyllitic, although excluded from *Rhacophyllites* on account of their involution. Again, *Phylloceras glaberrimum* Neumayr, and *Ph. psilomorphum* Neumayr, which, according to Geyer (1886), probably belong to *Rhacophyllites*, are referred (like *Ph. lunense* Meneghini) by most authors to the group of *Phylloceras heterophyllum*, also because they are involute. Their external saddles are diphyllic, as is also the case in *Ph. togatum* Mojs., although this form,[3] on account of its constrictions, is referred by

[1] The nepionic stage, which must agree with the larval development of that Triassic genus, will be dealt with later.

[2] A specimen of *Geyeroceras cylindricum* (Sow.), which I dissected by kind permission of the Keeper of the Geological Department of the British Museum, was unfortunately, owing to its preservation in brittle iron-oxide, not reducible to a sufficiently small diameter, and consequently the development of its suture-line could not be traced.

[3] According to Wähner (*op. cit.* pt. viii, 1898, p. 175) this is identical with *Rhacophyllites stella* Neumayr.

some authors to the group of *Phylloceras capitanei.* Another *Phylloceras*, mentioned by Neumayr (1879) from the *Psilonotus* Beds, has a larger umbilicus and less numerous constrictions, and therefore comes very near to the young *Rhacophyllites stella.* If we further remember that there are constricted and non-constricted *Rhacophyllites* of the *stella* group, and that the constrictions in '*Phylloceras*' itself differ widely, as is shown when comparing, for instance, *Ph. sylvestre* Herbich (1878) with the above-mentioned *Ph. togatum* Mojs., it will be seen that neither whorl-shape and involution, nor ornament and constrictions in the adult, will enable us satisfactorily to separate these ammonites into *Phylloceras* on the one hand and *Rhacophyllites* on the other. Evidence of the development alone (especially of the development of the suture-line) will permit us to approximate to a rational classification of these early forms.

Rhacophyllites might, as Pompeckj (1895, p. 39) suggested, be restricted to the ornamented forms, preferably the *transsylvanicus-diopsis* group. *Meneghiniceras* denotes the crenulate development, whereas *Dasyceras* and *Schistophylloceras* appear to be special lateral developments. The former is not identical with *Euphyllites*, as Prinz (1905) seems to think, since it has a rhacophyllitic suture and no constrictions; the latter may be used for the sulcate forms (*Sch. aulonotum* Herbich, and *Sch. sulcatum* Vadasz) which are restricted to the lowermost Lias. Carinate forms (not necessarily sulcate on casts) which appear at several horizons (*uermoesense*, pars in Wähner; *eximius* Hauer; *planispira* Reynès), but do not give rise to any progeny, cannot be satisfactorily separated as yet.

As has been stated before, all these forms, on account of their normally diphyllic saddles, appear to be descendants of *Discophyllites*, and are certainly not in the ancestry of the genus *Tragophylloceras* with its monophyllic external saddle. *Euphyllites*, however, which has a psiloceratid suture-line in addition to constrictions, appears to be more closely related to the stock which, later, produced *Tragophylloceras*.

It is by no means suggested that *Euphyllites* is in the direct line of ancestry of the genus *Tragophylloceras*. *Euphyllites* has compressed whorls, and begins to develop, not only strong lateral ornament,[1] but incipient crenulation of the periphery, such as is observed solely on body-chambers of *Tr. loscombi.* But the course of the radial line, the constrictions and the suture-line indicate close relationship. The suture-line is not unsymmetrical, as in *Psiloceras*, nor is the suspensive lobe so typically developed as it is in *Ps. calliphyllum* Wähner. The saddles, on the other hand, are triphyllic, although Wähner says that the external saddle is intermediate between *Psiloceras* and *Phylloceras* and, therefore, subdiphyllic. Wähner thinks it curious that in *Euphyllites*, as well as in *Phylloceras* (*Rhacophyllites*), two forms should occur

[1] The apparently big ribs of the innermost whorls are merely the raised portions of the lateral area between successive constrictions, and not costæ.

which are very close one to the other as regards external shape and yet have, the one a triphyllic, the other a diphyllic first lateral saddle. It seems to me, however, that the diphyllic and triphyllic saddle-endings, which are very often most difficult to distinguish, are of little importance if considered in the adult alone and without knowledge of their development. If *Rhacophyllites uermoesense* Herbich is as near to *Rh. stella* Sow. as Wähner[1] thinks, then the development of its principal saddles must resemble that of fig. 3, Pl. L, and be thus typically diphyllic. In *Euphyllites*, on the other hand, the development is apparently, like that of *Psiloceras*, monophyllic, with triphyllic endings in the adult. The resemblance of its triphyllic first lateral saddle and external saddle (the latter occasionally subdiphyllic) to *Rhacophyllites uermoesense* in the adult would thus be quite superficial.

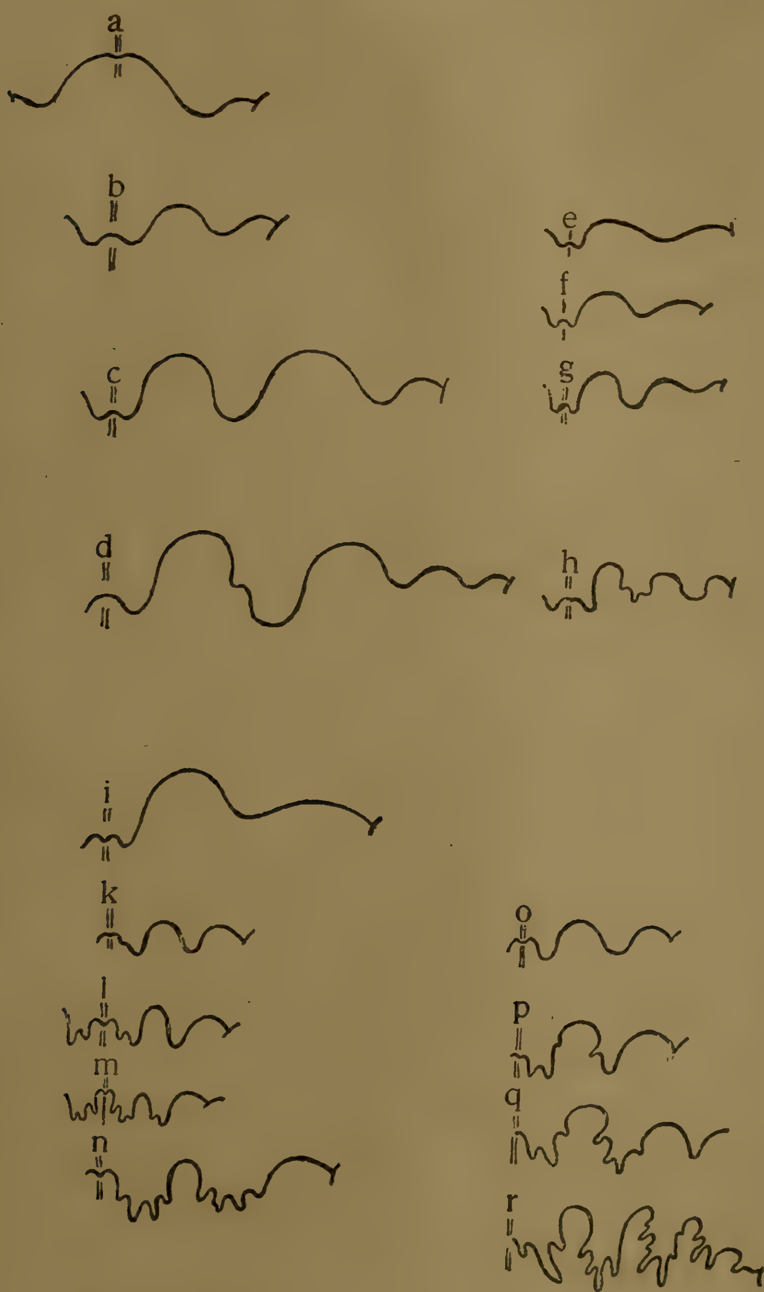
Euphyllites is included in what Prof. Diener (1908) called that remarkable stock of transitional forms between *Phylloceras*, *Lytoceras*, and *Psiloceras*, which proved the common origin of all Liassic ammonites. He would adopt Hyatt's family-name 'Pleuracanthitidæ' for this group, and look for the roots of this stock in the Triassic genus *Mojsvarites*.

Now *Pleuracanthites* is very near to *Analytoceras*: in fact, Wähner had called it 'a connecting link' between the families Ægoceratidæ (= Psiloceratidæ + Arietidæ) and Lytoceratidæ. But *Analytoceras articulatum* (Sow.) in whorl-shape and constrictions is again a morphic equivalent of the unknown *Tragophylloceras* ancestor, although characterized by an already distinct lytoceratid suture. Moreover, forms such as *Pleuracanthites polycycloides* Wähner, and *Parapsiloceras polycyclum* (Wähner), according to their author, must have been very near, morphologically and genetically, to the ancestor of *Psiloceras calliphyllum*. Consequently, *Pleuracanthites*, *Parapsiloceras*, and *Euphyllites* are, indeed, a transitional group which with *Ectocentrites*, might well be separated, as Prof. Diener has suggested.

The question now arises whether *Tragophylloceras*, which has morphic equivalents in *Phylloceras* (*Rhacophyllites*) as well as in *Analytoceras*, but the suture-development of which connects it more with the Psiloceratidæ, should be included in this transitional family of the 'Pleuracanthitidæ.' Its late geological age seems to be at first sight against this union, but it will be seen that the psiloceratid suture up to a comparatively late stage makes it truly a primitive genus; whereas, even morphologically, *Tragophylloceras* has hitherto occupied quite a distinct position among the Jurassic Phylloceratidæ. It is therefore considered that *Tragophylloceras* can more naturally be grouped with *Euphyllites* and the other primitive forms, than with the typical Phylloceratidæ. The term Pleuracanthitidæ Hyatt, as suggested by Diener is, perhaps, not quite suitable, since *Pleuracanthites* itself,

[1] *Rhacophyllites uermoesense* in Wähner's interpretation is too comprehensive, and includes a variety of forms which might very well be separated.

Fig. 3.—*Sutures of various ammonites.*



[*a–d* = *Tragophylloceras loscombi* (Sowerby): *a* = Primitive Goniatite stage; *b* = *Glyphioceras-Dimorphoceras* stage; *c* = *Monophyllites* stage; *d* = *Psiloceras* stage. *e–h* = *Monophyllites simonyi* (Hauer) after Branco. *i* = *Anthracoceras discus* Frech. *k–l* = *Dimorphoceras gilbertsoni* (Phil.); *m* = *D. looneyi* (Phil.). *n–o* = *Thalassoceras gemmellaroi* Karp. (*n* = adult; *o* = young). *p* = *Th. microdiscus* Gemm. *q* = *Th. varicosum* Gemm. *r* = *Ussuria schamaræ* Diener.]

with incipient carination, brings out the transition to *Lytoceras*, *Psiloceras*, and the Arietoids, but not the phylloceratid ancestry of the group. The term Pleuracanthitidæ, however, is here adopted, and it is suggested that the family be included as *Monophyllites–Mojsvarites* descendants in the superfamily Phylloceratida.

Finally, it may not be out of place to review the evidence regarding pre-Liassic ancestors of *Tragophylloceras* and the Phylloceratida. The sutures representing the 'Primitive Goniatite,' the '*Glyphioceras–Dimorphoceras*,' and the '*Monophyllites*' stages are again illustrated in text-figs. 3 *a*–3 *c* (p. 357). Figs. *e*–*h* show the closely-comparable development of the suture of *Monophyllites simonyi*, after Branco. It will be seen that the suture of an adult *Anthracoceras* (*Dimorphoceras*), shown in fig. *i*, differs only in the complication of the median saddle in the ventral lobe, a feature which characterizes the development *Dimorphoceras–Thalassoceras* (figs. *k*–*n*). Thalassocerata of the complicated *gemmellaroi* type, however, form a specialized lateral branch, and have no descendants in the Lower Trias; whereas from simple, more generalized and therefore plastic Thalassocerata (see figs. *o*–*r*), both *Ussuria* and *Ussurites* appear to have developed. Here the elaboration of the lateral elements takes the place of the complication of the ventral lobe in the older sequence *Dimorphoceras–Thalassoceras*. Now, in *Monophyllites* itself, which is shown by its suture to be nearly related to the ancestral stock that produced *Ussurites*, the first lateral lobe becomes subdivided before the ventral lobe, and this is also the case in *Tragophylloceras*; but it does not apply to all Phylloceratida, as the ontogeny of *Phylloceras heterophyllum* shows.

Again, we have seen that the ventral lobe of *Tragophylloceras* is considerably less deep than it is in *Monophyllites*, which is what we should expect in the later genus, considering the high ventral lobe of the adult *Monophyllites*. But, arguing phylogenetically from this, we should in the ancestral forms of this genus look for a deep ventral lobe. It is therefore probable that a primitive and originally (not secondarily) involute ammonoid of the *Thalassoceras microdiscus* pattern, with a deep ventral lobe, and itself the descendant of an involute glyphioceratid (*Anthracoceras*[1]), comes nearest the hypothetical *Monophyllites* ancestor. This generalized root-form persisted throughout, and, after one or two more or less futile attempts at specialization (resulting in *Thalassoceras*, the highest-developed ammonoid of the Permian, and in *Ussuria*-

[1] Prof. Frech (1899) derives *Anthracoceras* and *Dimorphoceras* from the evolute Devonian *Gephyroceras*, but it can much more naturally be attached to the involute Carboniferous *Glyphioceras* (*Beyrichoceras*), which has a similar suture and the subdivision of the median saddle in the ventral lobe just indicated, though in *Dimorphoceras* this subdivision becomes the prominent feature. Dr. Perrin-Smith (1913, p. 637), on the other hand, connects *Dimorphoceras* with *Aganides*, but the narrow, deep, and undivided ventral lobe of the latter genus is against this derivation.

Ussurites, the highest ammonites of the Lower Trias), began to develop rapidly with the *suessi* and *sphærophyllus* groups of *Monophyllites*, at the base of the Middle Trias.

Nomismoceras, which is erroneously regarded as the ancestor of *Monophyllites* by Prof. Haug (1908, vol. ii, pt. i, p. 860) and Dr. Perrin-Smith (1913, p. 650), is a dwarfed, lateral development off *Glyphioceras*, with extreme latumbilication setting in. *Popanoceras* and *Cyclolobus*, on the other hand, which are considered to be the ancestors of *Monophyllites* by Zittel (1910) and Prinz (1904), apparently lead to *Megaphyllites* and *Phyllocladiscites*: and we have already seen that a comparison of the suture-development in *Megaphyllites* with that of *Monophyllites* does not reveal any connexion of *Megaphyllites* and *Popanoceras* with the Monophyllitidæ. The question of relationship can only be settled definitely, however, when the ontogeny of these Permian and Triassic forms has been studied.

The following is suggested as an improvement on the existing classification :—

Glyphioceratida :
- Thalassoceratidæ :
  - *Dimorphoceras* — *Anthracoceras* — *Thalassoceras* — *Ussuria* — *Ussurites*.

Phylloceratida :
- Monophyllitidæ :
  - *Monophyllites—Mojsvarites.*
- Phylloceratidæ :
  - *Discophyllites* — *Phylloceras* — *Geyeroceras*—*Rhacophyllites*—*Dasyceras*—*Schistophylloceras*—*Meneghiniceras*—*Sowerbyceras.*
- Pleuracanthitidæ :
  - *Tragophylloceras* — *Euphyllites* — ? *Psilophyllites*—*Parapsiloceras*—*Pleuracanthites*—*Ectocentrites.*

In conclusion, I desire to express my best thanks to the authorities of the British Museum (Natural History) for permission to examine the material in their custody and to dissect certain specimens; to Prof. Paul Lemoine, of Paris, for information regarding A. d'Orbigny's figured specimens; to a number of friends, especially to Dr. Wyatt Wingrave and to Mr. J. Francis, F.G.S., for permission to examine their ammonites; and to Mr. C. P. Chatwin, for bibliographic assistance and for reading through the manuscript. My especial thanks are due to Mr. W. D. Lang, who has collected the material so admirably, and whose keen enthusiasm for research among the ammonites has greatly encouraged me in the preparation of this paper.

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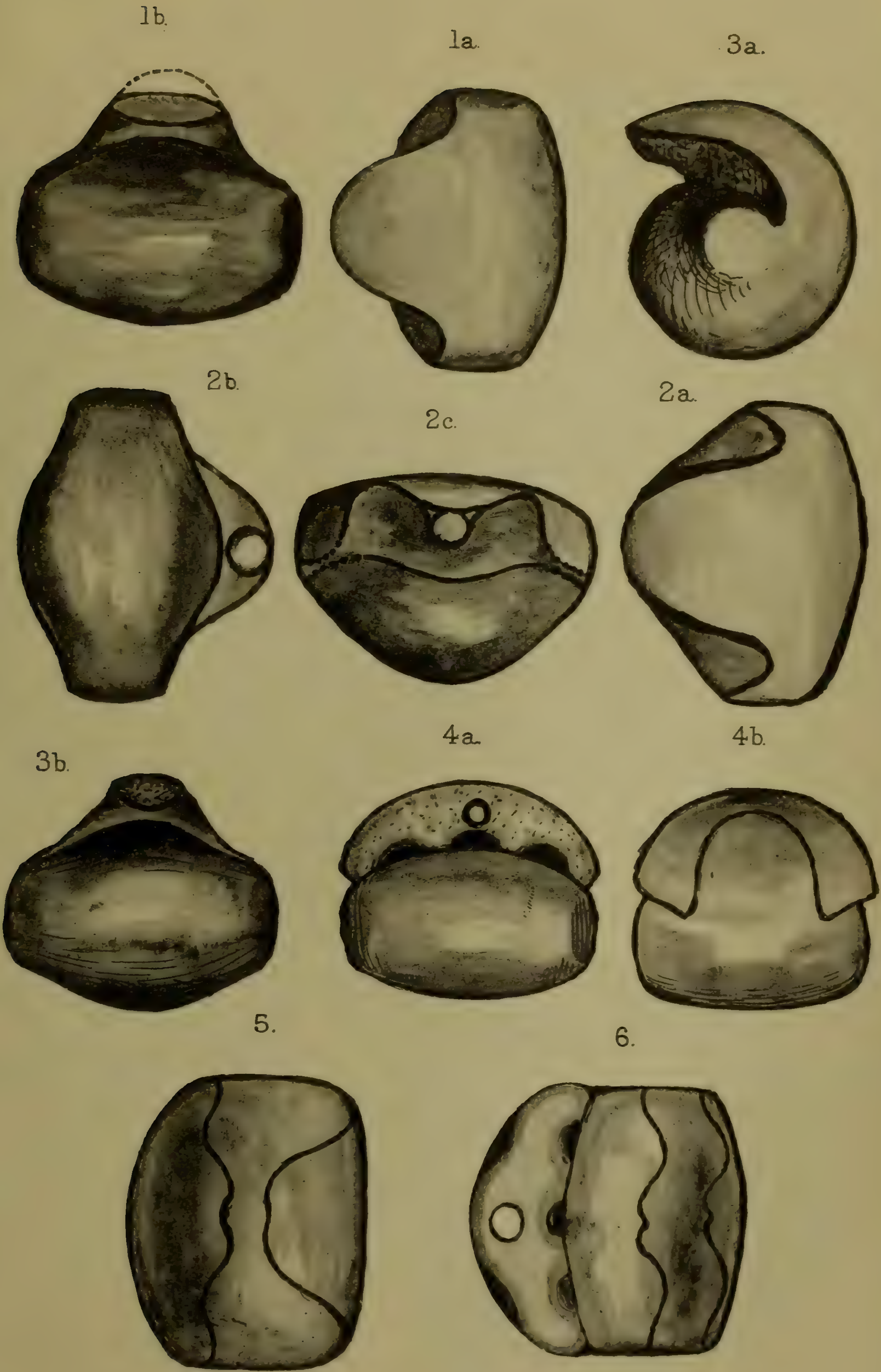
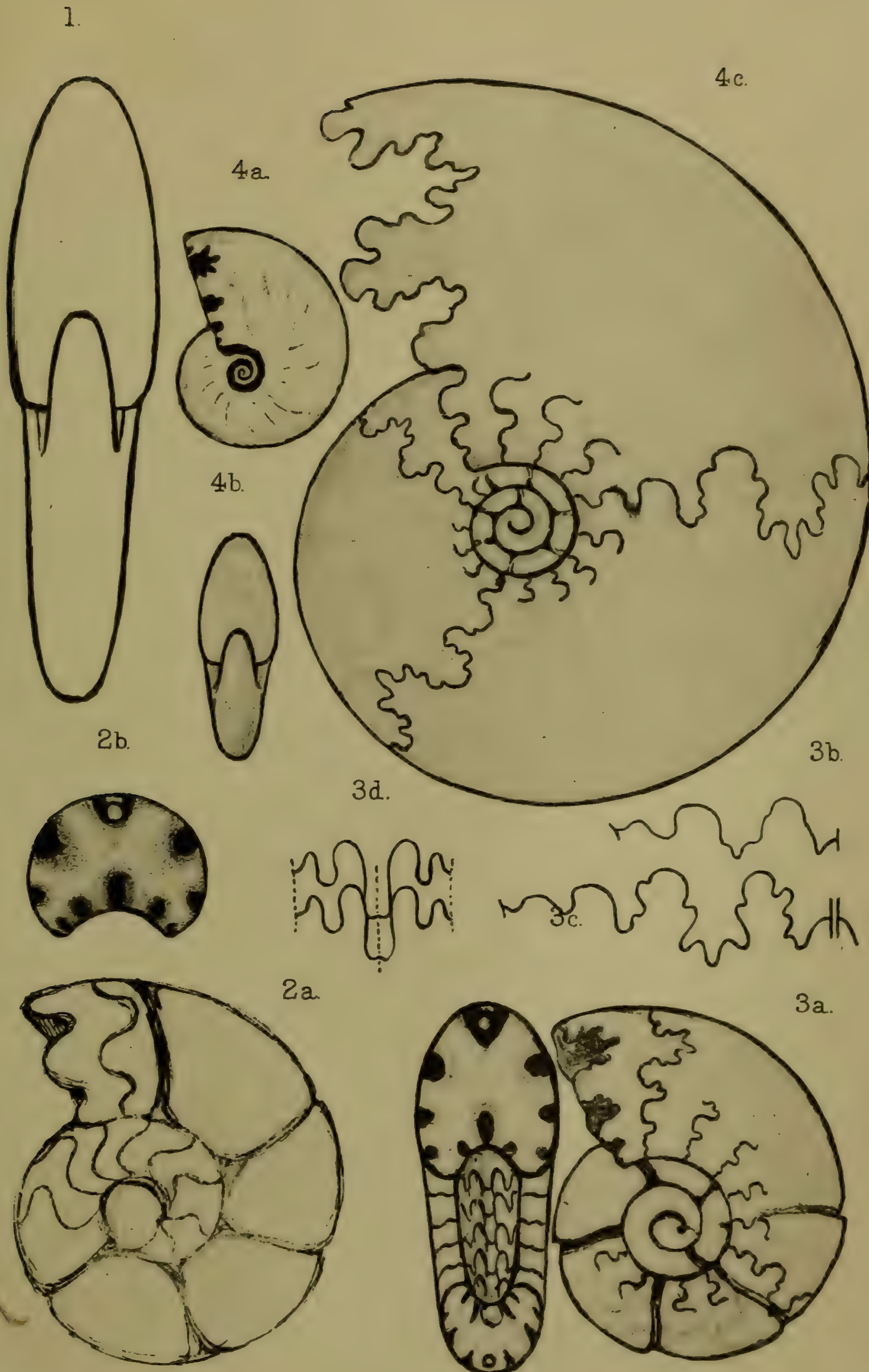


L.F.S., del.

Bemrose, Collo, Derby

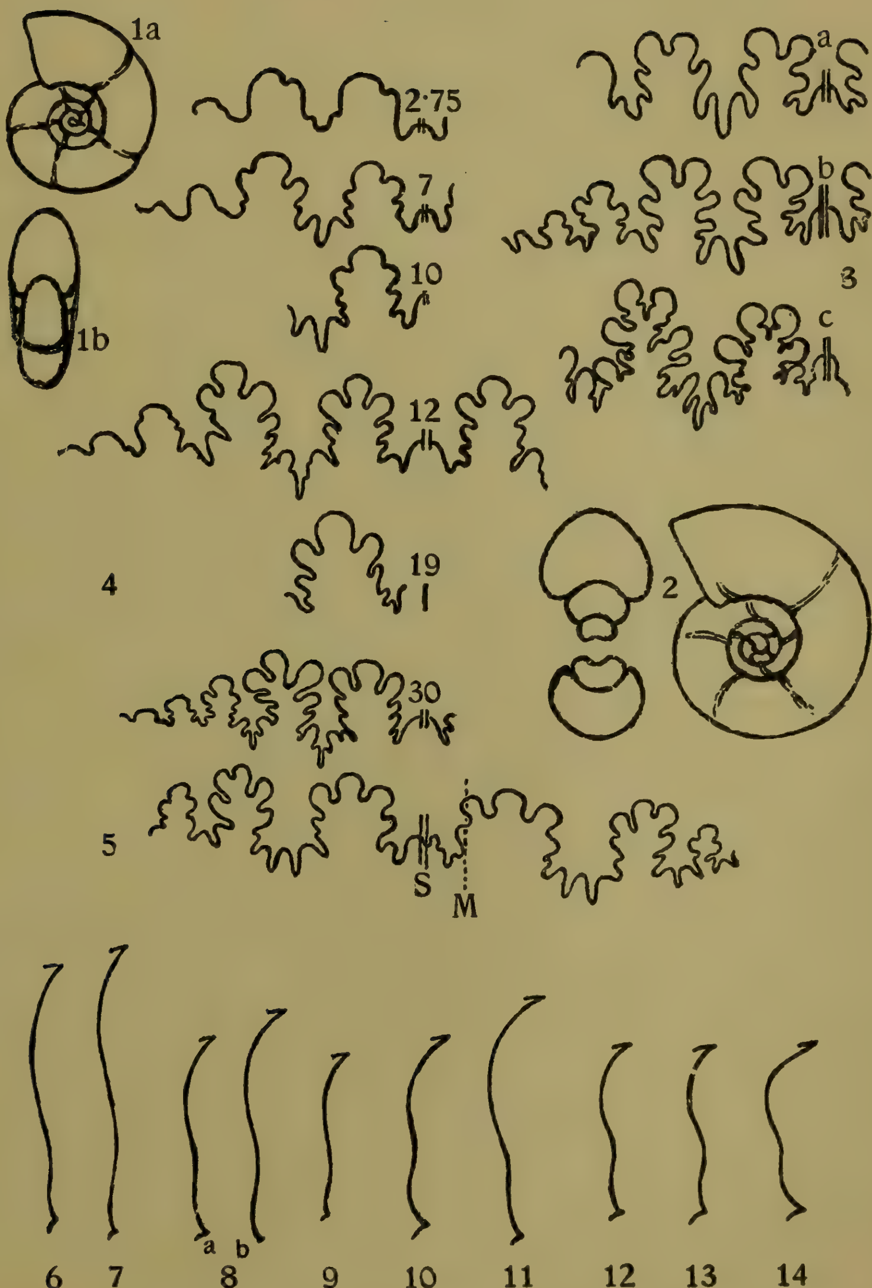
TRAGOPHYLLOCERAS LOSCOMBI (J. Sowerby).



L.F.S., del.

Bemrose, Collo., Derby

TRAGOPHYLLOCERAS LOSCOMBI (J. Sowerby).



SUTURES, RADIAL LINES, ETC. OF CERTAIN AMMONITES FOR COMPARISON WITH *TRAGOPHYLLOCERAS LOSCOMBI* (J. Sowerby).

EXPLANATION OF PLATES XLVIII–L.

Plate XLVIII.

Tragophylloceras loscombi (J. Sowerby), from 10 feet above the Belemnite-Stone on Black Ven, Charmouth.

[The numbers in parentheses refer to the collection of Mr. W. D. Lang. All the figures are enlarged, and represent internal casts in iron-pyrites.]

Figs. 1 *a* & 1 *b*. Protoconch from above and from below (1957 *a*). ×70.
2 *a* & 2 *b*. Protoconch from above and from below (2019). ×70.
Fig. 2 *c*. Frontal aspect do. ×70.
Figs. 3 *a* & 3 *b*. Lateral aspect and view from below (1999). ×70.
4 *a* & 4 *b*. The same specimen at the second suture. ×60.
Fig. 5. Specimen (1962 *a*) showing first and second sutures. ×70.
6. The same specimen at the seventh suture. ×55.

Plate XLIX.

Tragophylloceras loscombi (J. Sowerby).

(All the figures are enlarged, except fig. 1, which is of the natural size. Figs. 2–4 represent internal casts in iron-pyrites.)

Fig. 1. Front-view (outline) of Sowerby's type (B. M. No. 33425). 'Blue Lias' of Lyme Regis.
2 *a*. Young shell at the diameter of 1·2 mm, showing constrictions (1957*a*). From 10 feet above the Belemnite-Stone on Black Ven. ×35.
2 *b*. Section of the same.
3 *a*. Shell at the diameter of 2·8 mm. (1206). From a rainwashed slope at the horizon of the Upper Limestone, 35 feet above the Belemnite-Stone on Stonebarrow Cliff. ×18.
3 *b*. Suture at the diameter of 1·8 mm.
3 *c*. Suture at the diameter of 3 mm.
3 *d*. Internal (dorsal) suture at the diameter of 1·8 mm..
Figs. 4*a*–4*c*. The same specimen (1206) at a diameter of 6·25 mm.; *a* & *b* = side- and sectional views, $\times 4\frac{1}{2}$; *c* = side-view, ×15.

Plate L.

Figs. 1 *a* & 1 *b*. *Rhacophyllites stella* (Sow.). Lower Lias of Spezia (Brit. Mus. C 15569). Diameter = 6 mm. ×4.
2 *a* & 2 *b*. The same at the diameter of 4 mm. ×8.
3 *a*–3 *c*. Sutures of the same specimen:—3 *a* at the diameter of 4 mm.; 3 *b* at 6 mm.; 3 *c* in the adult.
Fig. 4. *Psiloceras* aff. *erugatum* (Bean-Phillips). *Planorbis* Zone of Robin Hood's Bay. Suture-development, enlarged. The numerals indicate the diameters in mm.
5. The same. Asymmetrical suture of another specimen. S = position of siphuncle; M = median line.
6. Radial line of *Tragophylloceras loscombi* (J. Sowerby) type.
7. Do. do. do. do. (in Wright).
Figs. 8 *a* & 8 *b*. Do. do. *Tragophylloceras ambiguum* (Simpson) in Buckman.
Fig. 9. Do. do. *Psiloceras planorbis* (Sowerby) in Quenstedt.
10. Do. do. *Euphyllites struckmanni* (Neum.) in Wähner.
11. Do. do. *Rhacophyllites uermoesense* (Herb.) in Wähner.
12. Do. do. *Mojsvarites planorboides* (Gümb.) in Pompeckj.
13. Do. do. *Monophyllites agenor* Mojs. (in Pompeckj).
14. Do. do. *Monophyllites simonyi* (Hauer) in Pompeckj.

Discussion.

Dr. A. M. Davies congratulated the Author on what appeared to be a very important piece of work. The species that he had chosen for investigation belonged to the first of the series of invading ammonites from the Mediterranean area which temporarily established themselves in Britain and, more frequently, in Germany. The paper was one to be read carefully and at leisure, and the connexions which it appeared to trace between Jurassic and earlier Ammonoids promised to be of great interest.

The President (Dr. A. Smith Woodward) expressed his gratification that a beginning had been made in studying in detail the growth-stages of the British Liassic Ammonites. Until all the principal types had been dissected in the skilful manner in which the Author had treated *Tragophylloceras loscombi*, there seemed to be little hope of making further progress in the interpretation and classification of these mollusca.

The Author, in reply, briefly thanked the President and Dr. A. M. Davies for their appreciative remarks, and the Fellows present for their kind reception of his paper.

17. *The* Topaz-bearing Rocks *of* Gunong Bakau (Federated Malay States). By John Brooke Scrivenor, M.A., F.G.S., Geologist to the Government of the Federated Malay States. (Read April 8th, 1914.)

[Plates LI & LII.]

Contents.

I. Introduction.

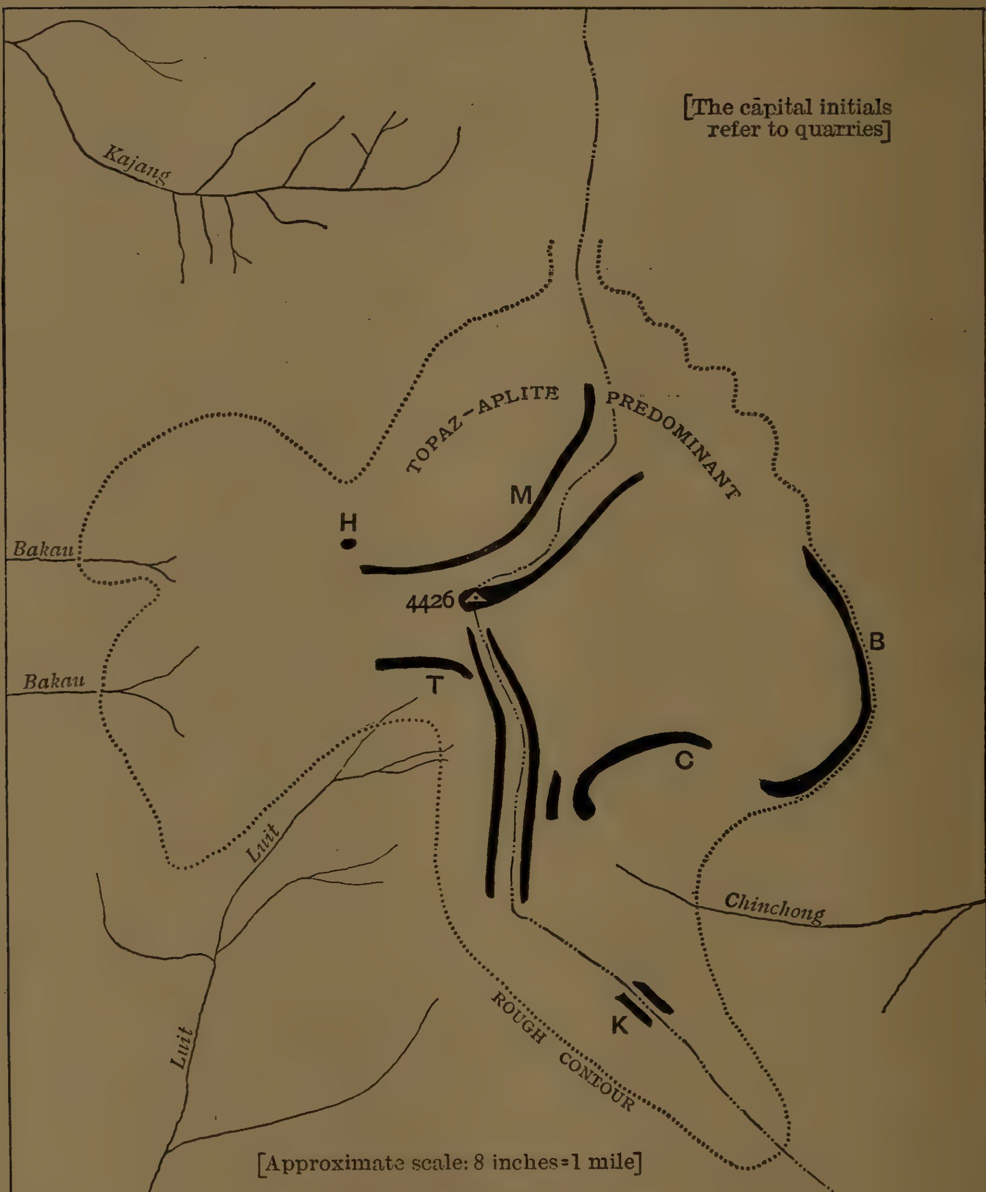
Igneous rocks with topaz as a constituent are well known, and it is unnecessary to give in detail the literature dealing with them. The best known are those in which the topaz is associated with cassiterite, and in such cases it is generally believed that the topaz has been formed by the tin-bearing media acting on felspar, converting part of the silicate of alumina into fluoride of alumina. The object of this paper, however, is to describe some clear sections in the Federated Malay States where two topaz-bearing rocks, both carrying cassiterite, are shown to have been intruded into porphyritic granite, and where the evidence is conclusive that both topaz and cassiterite are not alteration-products of previously formed minerals, but crystallized from the molten rock as topaz and cassiterite.

Gunong Bakau ('Gunong' is the Malay equivalent for mountain) is a mountain 4426 feet high, situated in the centre of the Main Range of the Peninsula, on the boundary between the two States, Selangor and Pahang. The name will not be found on any published map, but it will suffice to say that in the sketch-map accompanying my paper on the 'Geological History of the Malay Peninsula',[1] its position is near the source of the River Selangor, at the boundary of the State of that name.

The sketch-map accompanying the present paper (fig. 1, p. 364) gives some idea of the surroundings of the mountain. On the west are the sources of the Rivers Kajang, Bakau, and Luit; on the east is the source of the River Chinchong. The slopes of the mountain are steep, sometimes as much as 45°; but, until mining operations

[1] Q. J. G. S. vol. lxix (1913) pp. 343–71 & pl. xxxv.

Fig. 1.—*Sketch-map of Gunong Bakau and its immediate surroundings.*



[All the big veins are not shown; their course is roughly indicated by the heavy black bands.]

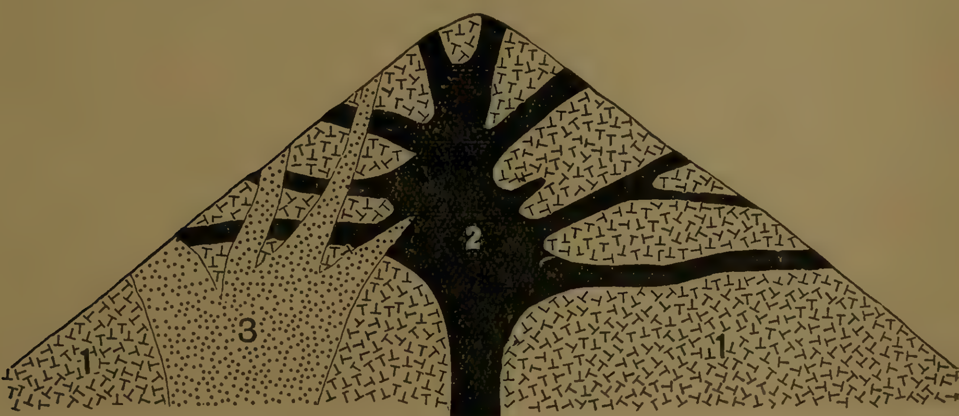
commenced, the whole of the peak was covered with dense vegetation. It is now the scene of considerable mining activity, and is a striking tribute to the perseverance of the two well-known Pahang miners, Mr. A. H. Bibby and Mr. J. Ruxton, to whom I am indebted for assistance in keeping pace with developments in the Chinchong Valley since 1904. I am also indebted to Mr. W. M. Mason for valuable help on the Selangor side of the mountain.

The history of the development of Gunong Bakau is noteworthy. In 1904, or perhaps earlier, Messrs. Bibby & Ruxton found in the Chinchong Valley numerous boulders of a rock consisting essentially of quartz, topaz, and cassiterite. The percentage of tin-ore was sufficient to stimulate a search for the source of the boulders, and in 1908 a lode was found on the north side of the valley, but it was not the topaz-bearing rock. The prospectors were finally rewarded by finding the topaz- and cassiterite-bearing rock *in situ* close to the top of Gunong Bakau, and it was proved later to extend to the Selangor side of the mountain and up to its summit.

II. Outline of the Geology of Gunong Bakau.

The geology of this part of the Main Range of the Peninsula has been kept in view, so far as circumstances permitted, ever since 1904; but it was not until October and November, 1912, that

Fig. 2.—*Diagram showing the relations of the porphyritic granite to the two intrusive rocks. (See p. 366.)*



[1 = Porphyritic granite; 2 = Quartz-topaz rock; 3 = Topaz-aplite. The central quartz-topaz vein has not been proved to exist as yet.]

it was possible to arrive at definite conclusions. I have no hesitation in saying that these conclusions would not have been possible, but for the extensive operations of the tin-miners and the assistance so readily granted by them.

Gunong Bakau is composed of porphyritic granite into which two rocks have been intruded, one after the other. The first rock

to be intruded was one in which quartz and topaz are constant constituents, and it is called in this paper the quartz-topaz rock. It occurs in veins, the biggest of which are about 15 feet thick. Some of these veins appear, at their outcrops on the side of the mountain, to be regular in form and lying almost flat, thus resembling sills. Others, however, are very irregular both in their course and in their form. Some are only an inch or so thick.

The second rock to be intruded was topaz-aplite. This cuts both the porphyritic granite and the quartz-topaz veins. On the north side of the mountain it forms large masses. On the south it is not so abundant, and one clear section shows distinct veins of it. I have called this rock an aplite, but it is rather coarse-grained for an aplite, and nowhere coarse-grained enough to be called a pegmatite, except as will be described later, at the border of certain parts of it.

Fig. 3.—*Sketch of exposure on Gunong Bakau, showing small veins of quartz-topaz rock* (2), *and topaz-aplite* (3) *cutting off the quartz-topaz veins on each side.*

[1=Porphyritic granite. Length of section = 21 feet; height = 9 feet.]

Fig. 2 (p. 365) shows diagrammatically the relations of the porphyritic granite, the quartz-topaz rock, and the topaz-aplite. The central vein of quartz-topaz rock has not yet been proved to exist, but the fact that Gunong Bakau stands out as a peak on the granite mass of the Main Range leads one to suspect some such hard core.

Fig. 3 is a sketch of an actual section, showing the quartz-topaz veins cutting the porphyritic granite, and the topaz-aplite cutting both these rocks.

III. Description of the Granite and Associated Rocks.

(1) The Porphyritic Granite.

The porphyritic granite is for the greater part weathered to a soft mass, owing to the kaolinization of the felspar; but in it are numerous 'core-boulders,' some of great size, consisting of fresh rock that has resisted weathering and affords good material for study. Both the fresh and the weathered rocks were examined by separation of the constituents in heavy liquids and by an electro-magnet, while the fresh rock was also examined by means of sections.

The porphyritic crystals are of orthoclase. In the mass of the rock are orthoclase and plagioclase, with maximum extinction-angles that reach 23°. Enclosed in the felspar a little muscovite is found. There is a little brown and also some blue tourmaline. A very small quantity of cassiterite and topaz was found in some specimens. In the fresh rock the chief mica is of a rich brown hue, and is apparently uniaxial. Careful spectroscopic tests proved a trace of lithia in this mica: the spectrum was very faint, but distinguishable. This mica may be called biotite with a trace of lithia.[1] Zircon and apatite are abundant.

There is no definite evidence that the tourmaline, topaz, and cassiterite, or any one of these minerals, are alteration-products of previously-formed minerals; but, in some specimens taken near the junction with a quartz-topaz vein, the tourmaline and topaz are more abundant than elsewhere. Both minerals in these cases may have been produced by media coming from the quartz-topaz vein. The muscovite enclosed in felspar may be an alteration-product of that mineral, but I have no proof of this. It might equally well be an original mineral, and the same must be admitted of the cassiterite, topaz, and tourmaline. No topaz or cassiterite has been seen in sections of the fresh rock, but topaz was detected by crushing and separating a large quantity of the fresh rock.

(2) The Quartz-Topaz Vein-Rock.

Distribution.—Some idea of the distribution of this rock may be gained from fig. 1 (p. 364). On the north one well-marked vein occurs in Quarry M. At the summit of the mountain and near the summit, as also along the ridge to the south as far as Quarry K, there are numerous outcrops of veins. Exposures of veins are seen in drives east of Quarry H, and one large circular section of a vein is exposed high up on a face in this quarry. In Quarry T another strong vein is exposed, and numerous smaller veins can be seen in a cutting made for some mine buildings hard by (fig. 3, p. 366). On the west the quartz-topaz rock is found as far down

[1] See J. D. Dana, 'A System of Mineralogy' 6th ed. (1892) p. 630—Analyses 6, 7, 29, & 30; also p. 631—Analyses 35 & 36.

from the summit as 460 feet and at a distance of about a mile. On the east, in Quarry B, is a strong vein about 15 feet thick, cropping out 280 feet down from the summit. This has been followed into the hill by means of drives. It appears to extend southwards towards Quarry C, where also is a thick vein, which may be the same as that in Quarry B, or a parallel vein at a higher level. Near Quarry C is evidence which leads one to believe that there may be three other veins, one cropping out below the other. Far to the south, about 2 miles away, the quartz-topaz rock has been found again, on the slopes of Gunong Raja, both by myself and by Mr. W. R. Jones, who also discovered a similar topaz-bearing rock near the foot of the Main Range in Selangor, some 10 miles distant.

Owing to the fact that the quartz-topaz rock does not weather readily, because it contains no felspar, the veins are easily distinguished from the soft, weathered porphyritic granite. (Pl. LI, fig. 1.)

Petrology.—When quite fresh the pure quartz-topaz rock is pale in colour, and of medium grain. It is hard. When exposed at the surface, it becomes slightly porous and pure white. This is owing to the slow solution of the quartz-grains and the alteration of the topaz to a fine, white, micaceous substance. No evidence has been found of the topaz weathering to kaolin. Masses of practically pure quartz-topaz rock are exposed on the south side of Gunong Bakau.

Quartz and topaz are, as already stated, constant constituents. Other constituents are cassiterite, tourmaline, arsenopyrite, pyrite, and white mica. The last is rare, and not noticeable in a hand-specimen, some being a product of weathering of the topaz, but some certainly an original mineral of the rock. Its scarcity may be judged from the fact that, although I watched the crushed stone from Quarry B passing over a Wilfley table for some time, I could not detect any. Sections of the rock show an occasional small flake. In Quarry M, however, there is throughout the rock a dark mica, easily distinguishable in a hand-specimen. The same mica occurs in patches elsewhere in the quartz-topaz rock. A little fluorite has been found in a section, and, as a result of treating large quantities of crushed rock, two zircon-crystals were detected. The significance of the extreme rarity of zircon will be dealt with later.

The quartz is in irregular grains, and calls for no special comment.

The topaz cannot be distinguished easily in any hand-specimen that I have seen. In sections under the microscope it is seen to have some straight boundaries, and in separations of crushed rock it sometimes shows fair crystal outline. It frequently occurs as minute grains enclosed in quartz. The cleavage parallel to (001) is well shown in sections. In some specimens, where there is little or no cassiterite, the topaz was found to constitute about 5 per cent.

of the rock. In other specimens, rich in cassiterite, it forms about 9 per cent. of the rock, with 9 per cent. of cassiterite. There do not appear, however, to be any definite relations between the percentage of topaz and that of cassiterite, as one vein was found rich in topaz and dark mica, but with no cassiterite.

The cassiterite is generally brown by transmitted light. In section it sometimes shows crystal boundaries, and in the crushed rock crystals with sharp outline were found. In one section a perfect little crystal was observed in quartz, and in another a perfect crystal was seen apparently enclosed in topaz. The cassiterite does not occur as veins or pipes in the quartz-topaz rock, but as a disseminated mineral. In Quarry B it forms about 1·75 per cent. of the rock. Occasionally one finds patches where the mineral has segregated to form a higher percentage than this. It never forms big crystals or big grains.

The tourmaline is not very common. Both brown and blue tourmaline occur. In some veins the mineral can be distinguished in hand-specimens as small dark spots.

Patches rich in tourmaline were found in Quarry C, one of them measuring 57 by 16 inches. In these patches the tourmaline occurs as aciculate crystals, and is associated with quartz, small clearly-defined crystals of cassiterite, and topaz. No zircons were found.

The dark mica, which occurs throughout the exposed portion of the vein in Quarry M, and as patches in other veins, is greenish, brown, or sometimes almost black, in hand-specimens. The axial figure does not open on rotation, so the mica is apparently uniaxial. It is rich in iron, and every specimen examined spectroscopically gives a strong reaction for lithia. It may be called, therefore, zinnwaldite rich in iron, and is comparable with Scharizer's protolithionite.[1] Cassiterite commonly occurs with this mica, and also topaz; but it has been remarked that where the mica is very abundant, the cassiterite is not abundant, and in some cases is entirely wanting. Where the mica occurs as a patch, the percentage of cassiterite in the mica-patch is distinctly less than in the surrounding quartz-topaz rock, where there is no dark mica. The mica and the topaz are seen in section to be closely associated, as though they had crystallized out from the molten vein-rock together.

The mica-patches vary considerably in size. One that I measured was 41 by 20 inches, but some are only an inch or two in diameter. They contain quartz, topaz, and sometimes sulphides, like the rest of the rock, and the only explanation that I can give of them is that the mica was segregated in certain parts of the still molten base. They differ from the familiar basic patches in granite, in that the surrounding quartz-topaz rock contains no dark lithia-mica; whereas, in the granite, mica occurs both in the patches and in the surrounding rock.

[1] J. D. Dana, 'A System of Mineralogy' 6th ed. (1892) p. 627; see also 'Rabenglimmer,' *ibid.* p. 626.

Pleochroic halos are abundant in the dark mica, and some of the inclusions bear a strong resemblance to zircon-crystals. A quantity of the mica was separated from the rock by an electro-magnet, and treated with the object of isolating the included minerals. Minute olive-green prisms of tourmaline were found, but it is not certain that these were surrounded by halos. A few well-formed zircon-crystals were obtained, and there can be no doubt that in some cases the halos do surround zircons, as in the biotite of granite.

(3) The Border of the Quartz-Topaz Veins without Dark Zinnwaldite.

The junction of the quartz-topaz veins with the weathered porphyritic granite is clearly defined, and where there is no dark zinnwaldite there is almost invariably a dark border to the quartz-topaz rock, varying in thickness from half an inch to 8 inches, that appears to be part of the vein-rock. This border is equally distinct in the thickest and in the thinnest veins, or perhaps it would be more correct to say that it is more distinct in the very thin veins, measuring only an inch across—because sometimes, in such cases, the dark borders on each side of the vein as seen in section are thicker than the vein itself. In the bigger veins the lines of division between the border and the granite and between the border and the quartz-topaz rock are both distinct, but in some of the smaller veins the dark border can be seen gradually passing into granite.

That this dark border of the quartz-topaz veins is a result of reaction between media that came off from the vein-rock and the porphyritic granite, and not a portion of the original vein-rock, is evident from the examination of sections, and therefore I propose to call it the reaction-border. The evidence is as follows:—Zircons, which are abundant in the granite, but extremely rare in the quartz-topaz rock, are common in the reaction-border. This was proved by separating the minerals in several crushed specimens. Some of the original biotite of the granite, bleached, but showing halos, and with secondary brown tourmaline formed in it, is found in the border. The colour of the border is dark, because of the abundance of tourmaline, which is nearly all brown. There is, however, some blue tourmaline. In addition to the tourmaline masses of fine-flaked muscovite occur, which suggest the alteration of the felspar of the granite; and, in this connexion, it is interesting to note that separations of the powdered rock afforded very little topaz. In one section a little topaz was seen in a mass of muscovite. No topaz was found in other sections. The presence of cassiterite could not be proved in the border, but in crushed rock one grain was found which may be that mineral.

The base of the reaction-border is quartz, and there is no felspar. The grain of the border is finer than that of the veins.

(4) Veins from the Reaction-Border invading the Porphyritic Granite.

In Quarry C a thin vein was found running off from the reaction-border into the porphyritic granite. It consists of brown and blue tourmaline, quartz, zircon, and muscovite, and appears to be due to the alteration of the granite along a fissure by media given off from the quartz-topaz vein. A similar vein was seen on the ridge south of the summit of Gunong Bakau, and another such vein was noted in Quarry B.

(5) The Border of the Quartz-Topaz Veins with Dark Zinnwaldite.

In Quarry M also there is a reaction-border between the vein-rock and the granite. In part it resembles the reaction-border described above, but generally the change effected in the granite is of a different nature. Fortunately sections could be cut showing both the altered porphyritic granite and the edge of the vein-rock. The granite is mainly altered to a quartz-muscovite-rock, the alteration extending only for a few inches at the most. Except at the immediate junction the altered granite is very soft. The muscovite occurs in felted masses of small flakes, and probably represents the felspar of the granite. Owing to the softness of the latter away from the immediate junction, and the general kaolinization by weathering of the felspar, this could not be proved by sections showing a gradual change. A little topaz was found that may have been derived from the felspar also. In the altered granite there is some altered biotite, as in the other type of reaction-border, but only a little tourmaline. The edge of the quartz-topaz vein is finer in grain than the body of the vein-rock. It contains on the whole as much topaz as the body of the rock, and in some cases more of that mineral. It generally contains more dark zinnwaldite. In one specimen the zinnwaldite, which is brown and more brightly coloured than in the body of the rock, but has been proved to be the same species, forms a distinct band, evidently the result of segregation during cooling. The greater abundance of the topaz in certain specimens admits of the same explanation. Sometimes, at the edge of the vein, one finds a beautiful intergrowth of the zinnwaldite and granular topaz. The felted masses of muscovite seen in the altered granite are not found in the border of the vein, but occasionally there is a quantity of white micaceous material formed by the alteration of the topaz. Tourmaline, generally of a distinct brown hue, occurs at the edge of the vein-rock, though not so abundantly as in the reaction-border.

The difference between the junction of the vein-rock with the granite in Quarry M, where the lithia-mica is abundant, and the junction between the two rocks elsewhere, is that in the former case the media coming off from the vein-rock produced a very thin band of greisen, while in the latter the result was a more distinct band of schorl-rock.

An alternative theory that suggests itself regarding the schorl-rock, is that the tourmaline may be in part the result of segregation from the vein-rock on the cool margin of the vein, but this could not be applied to some of the very small veins, where the reaction-border, full of tourmaline, is larger than the vein itself, in which tourmaline is not very common. Moreover, if the abundant tourmaline of the reaction-border were even in part a result of segregation, we should expect to get abundant topaz also (as in the clear case of segregation in Quarry M), but no case of a reaction-border with abundant topaz has been found. The explanation of the abundant tourmaline must be that the media contained more boron than in the case of the vein in Quarry M.

(6) The Topaz-Aplite.

The quartz-topaz veins do not contain any felspar, but in the topaz-aplite felspar is abundant. Generally it is almost completely kaolinized, but rock was found fresh enough for cutting sections. The following minerals occur :—

Quartz : this is common.
Orthoclase : highly kaolinized.
Plagioclase : not so much altered as the orthoclase, and showing extinction-angles as high as 20°.
Topaz : where the rock is too soft for sections to be cut, the topaz has been almost entirely altered to a micaceous mineral. Consequently, it is difficult to say how the amount compares with the amount present in the quartz-topaz rock. The sections cut show less than is found generally in the other rock, and probably the amount throughout was less.
Pale-brown mica : not abundant.
Muscovite : not uncommon.
Cassiterite : not abundant, in irregular grains.
Tourmaline : brown and blue ; not abundant ; some enclosed in fresh felspar.

In one of the drives near Quarry H a modification of this aplite occurs, with very abundant dark zinnwaldite, rich in iron, and apparently uniaxial like the mica in Quarry M. The bulk of the rock is formed of potash-felspar, but there is a little topaz and a little cassiterite.

In Quarry H, again, a nest of lithia-mica was found in a rock believed to be part of the aplite-intrusions. In this mica the axial figure opens slightly.

Numerous sections occur where the topaz-aplite may be seen cutting the quartz-topaz veins. No evidence was noted of reaction between the two rocks or the media carried by them. Where the aplite cuts the granite, there is no marked alteration of the latter as in the case of the quartz-topaz veins.

Two occurrences of pegmatite have been noted in connexion with the topaz-aplite. One is in the underground workings near Quarry B. A section of topaz-aplite is exposed showing the junction with the porphyritic granite, and from the aplite a thin vein of pegmatite with a border of schorl-rock protrudes into the granite.

The other case is in the underground workings of Quarry M. Here the junction of the topaz-aplite with the porphyritic granite is marked by a border, about half an inch thick, of pegmatite.

(7) Ore-Bodies believed to have been formed by Media from the Topaz-Aplite Intrusions.

Except in one spot, the topaz-aplite has not proved to be worth working for tin-ore, but in Quarry H certain ore-bodies were found some time ago, and one was found in the Chinchong Valley (see above, p. 365). Except for specimens, these ore-bodies have all disappeared now; but it was evident that they were the result of the alteration of pre-existing granitic rocks, and probable that the media which effected the alteration came from the aplite-intrusions. The evidence on the latter point is not so clear as it might be, but it need not be discussed here, as the ore-bodies are merely mentioned in order that emphasis may be placed on certain points that mark them off as distinct from the quartz-topaz rock.

In the first place no topaz was found in them. They contained little quartz, but a large amount of pale-green mica, which is practically colourless in thin sections. Where the ore was very rich the rock consisted of nothing but cassiterite and mica. Where it was poor, in Quarry H, it was felspathic, and two micas were distinguished: a mica with calcite as an alteration-product and the figure of a uniaxial mineral, believed to be the original mica of the rock in which the ore-body was formed; and a biaxial, secondary mica, largely developed in the felspar of the original rock. None of the mica from these ore-bodies in Quarry H gave a reaction for lithia. In the ore-body found in the Chinchong Valley, the powdered rock gave a very faint reaction for lithia, which was believed to come from a small quantity of mica having the axial angle of ordinary zinnwaldite. The rest of the mica in this ore-body had a small axial angle, excepting a trace with the figure of a uniaxial mineral, that might have been the original mica of the rock in which the ore-body was formed.

These ore-bodies then, formed by the alteration of granitic rocks, had no topaz, and with the exception just noted, no lithia-mica: but they contained abundant secondary mica that was distinctly biaxial.

The quartz-topaz veins and the topaz-aplite, on the other hand, have abundant topaz, no secondary mica (except that formed by the weathering of the topaz), while they do contain a dark lithia-mica, rich in iron, that has the habit of an original rock-constituent.

IV. The Faults.

There are numerous small faults cutting the granite, quartz-topaz veins, and aplite of Gunong Bakau. The amount of throw is small. The largest throw that I could measure was less than

10 feet. Generally the throws are about 1 to 3 feet. In Quarry H there are some well-marked slickensides, but the effect of the faults on the ore-bodies worked there was not appreciable. In Quarry C there is some evidence of movement along the top of the quartz-topaz vein, between the schorl-rock and the unaltered granite.

Faults such as these are common throughout the granite-masses of the Malay Peninsula. They probably mark the final adjustments of the cooled magma, and perhaps also faults due to earth-movements during the Tertiary Period. In one place, about 15 miles from Gunong Bakau, I have seen evidence of a big fault; but, on the whole, the faults cutting the granite and associated rocks are of no structural importance. This is certainly the case on Gunong Bakau.

V. Origin of the Quartz-Topaz Vein-Rock.

The foregoing description of the rocks exposed on Gunong Bakau, although condensed, will, it is hoped, suffice to show that we are dealing with a very interesting piece of petrography. That the quartz-topaz vein-rock consolidated from a molten state, and was not formed by the alteration *in situ* of a pre-existing rock, is in my opinion beyond doubt; but, before we discuss the possible changes in the granite magma that led to its intrusion into the porphyritic granite, it will be as well to adduce in detail the evidence on which this opinion is based. One reason why this is advisable is, that any one who had seen a hand-specimen only of the rock, would, in view of the literature on rocks with topaz and cassiterite, expect to find that it had been formed by the alteration of another rock; and, in fact, in a previous publication I gave expression to such an expectation myself, fortunately with a certain amount of reserve.[1]

The study of the quartz-topaz veins has been particularly interesting to me, because some years ago I had an opportunity of studying in equal detail a typical case of the formation of greisen with topaz in Cornwall,[2] and the points of difference between the two rocks have proved to be very instructive.

The clearest way of giving the evidence which militates against the quartz-topaz rock being an alteration-product such as the Cligga-Head greisen, is to employ the device of *reductio ad absurdum*, and to assume for the sake of argument that the veins were formed in the same manner. We are then confronted by the following difficulties:—

(1) In typical greisen-veins there is the clearest evidence of alteration extending from a fissure and gradually dying away at a distance from the fissure. In the quartz-topaz veins no such

[1] 'The Geology & Mining Industries of Ulu Pahang' Kuala Lumpur, 1911, p. 24.

[2] 'The Granite & Greisen of Cligga Head (Western Cornwall)' Q. J. G. S. vol. lix (1903) pp. 142–59.

fissures have been observed, and the vein-rock, rich in topaz, ends abruptly against the granite, which, however, has been altered for a few inches by emanations from the vein-rock to form familiar pneumatolytic modifications.

(2) If the quartz-topaz rock is an alteration-product, then we must assume that the reaction-borders of schorl-rock and greisen mark the farthest extent to which the alteration reached. Then why is the vein-rock so dissimilar from the rock that is clearly an alteration-product? It should be the same. Where the reaction-border of schorl-rock occurs, we should have a solid vein of nothing but schorl-rock. Where the reaction-border is of greisen, we should have a vein of nothing but the same rock. To put these objections in another form:—

(*a*) Why does the proportion of topaz, so abundant in the vein, suddenly drop almost to vanishing-point in the reaction-border?
(*b*) Why does the cassiterite, common in the vein, practically disappear in the reaction-border?
(*c*) Why are not the masses of white mica that are found in the reaction-border found also in the vein-rock?
(*d*) Why is tourmaline so abundant in the schorl-rock reaction-border, and not abundant in the vein, from which the schorl-rock is separated by a sharp line of division?
(*e*) Why are zircons common in the schorl-rock reaction-border and so rare in the adjacent vein-rock?

(3) If the quartz-topaz rock is an alteration-product, then the iron-rich zinnwaldite is an alteration-product, as it is not the same mica as that in the granite. Then it must have been formed from something. In greisen the secondary mica is believed to have been formed from felspar. But in Quarry M we observe masses of white mica in the altered granite, formed from felspar in all probability, and the zinnwaldite is distinct from this mica. Moreover, the zinnwaldite has included zircons with pleochroic halos. Were these zircons originally in felspar-crystals waiting for the formation of the zinnwaldite? [1]

(4) If the zinnwaldite originated by alteration of some mineral in the granite, since the granite is much the same in composition throughout the area under discussion, why do we not find the zinnwaldite in all the veins? and why do we find it in isolated patches?

(5) Why in Quarry M do we get finer grain at the edge of the vein, suggesting quicker cooling, and sometimes a higher percentage of zinnwaldite and topaz suggesting a segregation of these minerals in the part of the vein that first became solid?

(6) Finally, why were the ore-bodies mentioned above as occurring in Quarry H and in the Chinchong Valley, ore-bodies that

[1] In R. Beck's 'The Nature of Ore-Deposits' (Engl. transl. by W. H. Weed, vol. i, p. 200) a greisen from Banka is figured showing 'mica with dark aureoles round zircons.' This figure resembles closely sections of stone from the vein in Quarry M on Gunong Bakau. It is evidently held to be an alteration-product (*op. cit.* p. 201), but how the zircons got into the lithia-mica is not explained.

were certainly formed by the alteration of pre-existing rocks, markedly different from the quartz-topaz rock (see the points of difference enumerated above)?

Fig. 3 (p. 366) shows better than any verbal description how the quartz-topaz veins occur, and that sketch, with the evidence just adduced, must, I think, sweep away all doubt about the rock having consolidated as it is now with quartz and topaz as original constituents.

The origin of the rock led to a difficulty in assigning to it a name. I have referred to it in local publications as the 'Chinchong rock' or the 'quartz-topaz-cassiterite rock'; but, after seeing it *in situ*, I sought for a better appellation. Where the iron-rich zinnwaldite occurs the rock might be called a greisen, indeed a very similar rock has been figured as greisen.[1] But, although greisen is not necessarily an alteration-product,[2] most of the well-known examples have been formed by pneumatolytic changes, and the chief minerals of greisen are quartz and mica, the mica being usually white. This is not a fatal objection to calling the rock in Quarry M greisen, but that name cannot be applied to the other veins, where mica as an original constituent of the rock plays a part less important than apatite in granite. By no stretch of imagination can the main constituents of the veins, apart from that in Quarry M, be said to be quartz and mica, and therefore the

[1] R. Beck, 'The Nature of Ore-Deposits' [Engl. transl.], vol. i, p. 200.

[2] See A. Harker, 'Carrock Fell: A Study of Variation of Igneous Rock-Masses—Pt. II, The Grainsgill Greisen,' Q. J. G. S. vol. li (1895) pp. 139–47. On p. 142 the author states that 'these Cumbrian quartz-mica rocks differ in some respects from typical greisens, such as those of Cornwall and Saxony.' On pp. 142, 143 the author writes of the 'topaz, tinstone, and other minerals characteristic of the true greisens.' That these minerals occur in connexion with greisens is of course admitted, but I think that their importance is now somewhat overestimated. Dr. J. S. Flett, in the 'Geology of the Land's End District' (Mem. Geol. Surv. Expl. Sheets 351 & 358, 1907) gives an account of some Cornish greisens (see pp. 57, 58, 66). He says on p. 57, 'Topaz is very commonly, though not constantly, present.' On p. 66, in the description of the 'greisening' of elvans there is no mention of topaz, but tin-ore is said to occur. Dr. W. Lindgren in 'Metasomatic Processes in Fissure-Veins' (Genesis of Ore-Deposits) says, on p. 540, that greisen is a granular rock consisting chiefly of quartz, topaz, and white mica, thus making the topaz more important than the mica; and, on p. 544, the same author says that the name greisen ought to be reserved for the granular alteration-products of granite consisting of 'quartz, lithion-mica, topaz, and cassiterite.' It is difficult to agree with this. Reference to text-books will show that greisen is generally regarded as consisting essentially of quartz and mica. The other minerals play the part of accessories. F. Zirkel ('Petrographie' 2nd ed. 1894, vol. ii, p. 122), however, regards the lithia-mica also as an accessory, and the same view is taken by H. Rosenbusch ('Mikroskopische Physiographie der Massigen Gesteine' 3rd ed. 1896, p. 83). These authors regard the change from felspar to quartz as the most important feature of the rock, but the Cornish examples show that the production of secondary mica is equally important. I have a specimen in my office of Zinnwald greisen, obtained from a dealer. It is not like the Cornish greisens, but resembles the rock in Quarry M on Gunong Bakau. The amount of topaz is small, and what is present is closely associated with the zinnwaldite, as in the Gunong Bakau rock.

name greisen is inapplicable. The topaz, which is far more abundant than, and differs in habit from, the topaz in any greisen that I have examined, suggests the name 'topazfels,' but here again the name is associated with the alteration of a pre-existing rock. The best-known example of such an alteration is the altered quartz-porphyry of Mount Bischoff, in Tasmania; and, after reading W. von Firck's paper,[1] and comparing the plates of microphotographs accompanying the paper with the quartz-topaz rock, I can say that the latter is a very different thing.[2] For example, I have not seen in any of the quartz-topaz veins even a suggestion of a pseudomorph of topaz after felspar.[3] The only reference that I can find to a rock like the quartz-topaz rock is in Rosenbusch's 'Mikroskopische Physiographie der Massigen Gesteine' 3rd ed. (1896) p. 84, where, in describing the Altenberg 'Zwitter,' he says:—

'In diesem normalen Zwitter tritt in geringer Verbreitung eine graue Varietät ohne grünen Glimmer auf. Sie besteht aus 71.36 % Quarz, 27.21 % Topaz, und 1.43 % Zinnstein.'[4]

The rock in Quarry M and the mica-patches elsewhere might then be called greisen; but, as the name is not applicable to the greater number of the veins, and as its use in the case of Quarry M might give rise to a misconception regarding the origin of the rock, I name the vein-rock generally by its two constant constituents. In the case of the extraordinary tourmaline-corundum rocks of Kinta, I resisted the temptation to inflict a new name on petrology, and have less difficulty in doing so now. Descriptive names embodying the main constituents, although sometimes clumsy, are greatly preferable to names based on localities which convey no further information about the rock; and, as regards the Gunong Bakau rocks, the main point is to avoid giving a false impression of their mode of origin by the misuse of existing terms.

There is no question about the topaz-aplite having consolidated direct from the molten material.

VI. Magmatic Processes that may have led to the Formation of the Gunong Bakau Rocks.

Not the least interesting problem raised by the study of these rocks concerns the processes in the granitic magma to which their

[1] 'Die Zinnerzlagerstätten des Mount Bischoff in Tasmanien' Zeitschr. Deutsch. Geol. Gesellsch. vol. li (1899) pp. 431–64.

[2] I am indebted to Mr. W. H. Twelvetrees, Government Geologist of Tasmania, for information regarding this rock.

[3] See *op. cit.* pl. xxvii, fig. 2.

[4] Zirkel mentions the same rock, 'Petrographie' 2nd ed. (1894) p. 124; Prof. A. Lacroix describes a granulite in the Haute-Vienne with quartz, lepidolite, albite, and topaz ('Minéralogie de la France & de ses Colonies' pt. i, pp. 62–64). A granulite with cassiterite, but no topaz, is described by Dr. L. L. Fermor (Rec. Geol. Surv. India, vol. xxxiii, 1906, pp. 235, 236). The double use of the word granulite in petrology would make its employment for the Gunong Bakau rocks objectionable, even if the quartz-topaz rock contained felspar.

formation may have been due. In the first place, there is a minor point that should be made clear. Gunong Bakau is a peak situated almost in the centre of the granitic Main Range of the Peninsula. There are other instances of tin-deposits not very far away similarly situated, and at first sight they all seem to contradict experience elsewhere, namely, that tin-deposits are generally found on the periphery of a granite mass. This, however, is not the case. In three localities on the Main Range sedimentary rocks are known to cap the granite near the centre of the range. In one of these, quartzite and phyllites cap the highest peak in the whole chain, Gunong Riam, or Kerbau, in the Kinta District (altitude, 7160 feet). There is, then, good reason to suppose that the present ridge of the range coincides approximately with the top of the original granite intrusion, and we can therefore regard Gunong Bakau as being near the vertical limit of the granite-mass. This preservation of the limits of the granite-mass is one of the factors that has endowed the Malay Peninsula with such enormous mineral wealth as compared with Cornwall, where the granite-masses have been planed down by denudation.

The current theories postulating the intrusion of pegmatite and the formation of tin-deposits in a granite-mass by pneumatolytic action during the last stages of the consolidation of a granitic magma, are now so familiar as to need no exposition here. It is clear, however, that in the case of the rocks of Gunong Bakau there were magmatic processes in operation that differed from those which are believed to have generally taken place.

The sequence of events in the mass now forming the peak of Gunong Bakau is clear. First, the porphyritic granite consolidated; then the quartz-topaz veins were intruded; and then the topaz-aplite arrived.

First, granite rich in felspar consolidated; then, a rock without any felspar was intruded into it; and then, another rock rich in felspar invaded the mass of granite.

Therefore, before the last part of the magma capable of affording felspar had consolidated, veins of a rock without any felspar at all were intruded. This is not what would be expected in the differentiation of a magma, and it is interesting to consider how it can have come about.

It cannot be proved that the topaz and tourmaline found in the granite are, even in part, original rock-constituents, but they may be so. This, and the proved trace of lithia in the biotite make one suspect that, before the granite consolidated, fluorine, boron, and lithium were present throughout the mass in small quantities. As the last products of an acid magma are generally richer in these elements than the granite itself, we may suppose that a concentration of them takes place as solidification progresses. How this takes place and how the elements move in the magma we cannot tell, but they are probably combined with other elements and in the state of gas, and I think it is possible to account for the quartz-topaz veins by some such hypothesis as the following.

Let us suppose that in the depths of the igneous mass there was a magma which, if undisturbed, would have crystallized out as a rock composed chiefly of potash-felspar, quartz, and a mica rich in iron. If this magma were invaded by a volume of gas as a huge bubble rising from below, where it had collected in a part of the magma on which it could not react, and if the gas were composed of fluorine partly combined with tin, together with boron and lithia in some form, then the molecules of 'nascent felspar' etc., would be attacked, violently where the bubble rose, and less violently in its neighbourhood when the gases spread. They would be forced to rearrange themselves in combination with the attacking gases, and the heat generated would raise the temperature sufficiently to lead to an immediate irruption of this part of the magma into the consolidated granite above. As the molten mass rushed through the comparatively cool rock the molecules would begin to form crystals. The alumina of what had been nascent felspar-groups crystallizes out in combination with fluorine and silica to form topaz; the molecules that might have been mica without lithia crystallize as zinnwaldite and as tourmaline; the potash of what had been nascent felspar goes into both these minerals; and the tin crystallizes out as cassiterite. The base in which these minerals were formed was an excess of silica, and before this solidified as quartz there would be nothing to prevent some degree of segregation of the earlier-formed minerals.[1] This will explain the abundance of zinnwaldite in Quarry M and its absence elsewhere except in the mica-patches. It also explains the irregular, sporadic distribution of cassiterite, and the absence of any fixed relation between the amount of cassiterite and that of topaz.

The chemical reactions in the magma would certainly be more complicated than is indicated above, but the course of events sketched will suffice to show on what the hypothesis is based. It is hardly necessary to endeavour to work out complete formulæ for the magma, the gases that attacked it, and the resulting minerals.

The reaction-borders of schorl-rock and greisen are easily accounted for by this hypothesis. They are the effect of the surplus gases entangled in the solidifying rock on the granite walls of the veins, and the total absence of felspar in the quartz-topaz rock is due to there having been an excess of these gases.

Meanwhile, during the cooling of the quartz-topaz rock, the remainder of the magma was being acted upon slowly by the smaller quantities of gas that spread out from the bubble. There was not

[1] Without segregation one could not expect to have a rock very rich in topaz. In the case of a pure orthoclase-magma, the percentage of alumina would be 18·4. Since in 100 parts of topaz there are 56·5 of alumina, with 18·4 per cent. of alumina available only 32·6 per cent. could be formed if the magma were invaded by fluorine unaccompanied by more alumina. It is unlikely that the magma would be a pure orthoclase-magma, therefore the percentage of topaz possible would be lower than 32·6. In the case of greisen bordering a fissure-vein with distinct walls, I do not see how segregation of minerals could take place without the effacement of the walls of the fissure-vein.

enough fluorine to convert all the nascent felspar into nascent topaz, but it seems that there was enough lithia to change the nascent iron-mica to nascent zinnwaldite. The chemical energy of the gases was practically expended in the magma; and so, when the mass rose to form the topaz-aplite, and, by segregation, the small quantity of its modification rich in zinnwaldite, it had no entangled gases to attack the porphyritic granite or the quartz-topaz veins, except in the possible cases of the schorl-rock bordering the pegmatite-vein mentioned earlier as coming off from the aplite, the rich ore-bodies in Quarry H, and the similar ore-body in the Chinchong Valley. These ore-bodies must be admitted to constitute a difficulty in the hypothesis. It is possible that the aplitic magma in its upward course redissolved part of the quartz-topaz rock, or other consolidated parts of the magma containing tin-ore, and that the resulting gases formed the ore-bodies; but the non-occurrence of topaz in them is an objection to redissolved quartz-topaz rock being the source of the rich tin-ore.

VII. Summary.

The main points of this paper may be summarized as follows:—

Gunong Bakau is a peak 4426 feet high in the Main Range of the Malay Peninsula. It is composed of porphyritic granite, into which have been intruded veins of quartz-topaz rock, and, at a later date, masses and veins of topaz-aplite.

The quartz-topaz rock has quartz and topaz as constant constituents. Other important constituents, which, however, are not always found, are cassiterite, zinnwaldite rich in iron and with the axial figure of a uniaxial mineral, and tourmaline. The zinnwaldite is only known to occur in considerable quantity in one vein. Elsewhere it is sometimes found forming patches in the quartz-topaz rock.

The topaz-aplite contains a small amount of cassiterite.

Where the quartz-topaz veins cut the granite, a 'reaction-border' of schorl-rock, and in one case of greisen, is found. These reaction-borders differ widely from the veins themselves.

Evidence is given in detail, showing that the quartz-topaz vein-rock is not an alteration-product of a pre-existing rock, but was intruded as a quartz-topaz magma.

Ore-bodies formed by pneumatolytic alteration of granitic rocks were once worked on Gunong Bakau, and they differed markedly from the quartz-topaz rock.

It is believed that the difference between the familiar pneumatolytic products, schorl-rock and greisen on the one hand, and the quartz-topaz rock on the other, is that in the former case rocks that had consolidated on the edge of a granite-mass were altered by media coming from deeper parts of the mass; whereas in the latter an accumulation of similar media attacked part of the still molten magma deep down in the igneous mass, and the heat generated by the reactions that took place caused the portion of

Fig. 1. A Quartz Topaz Vein in Quarry C:

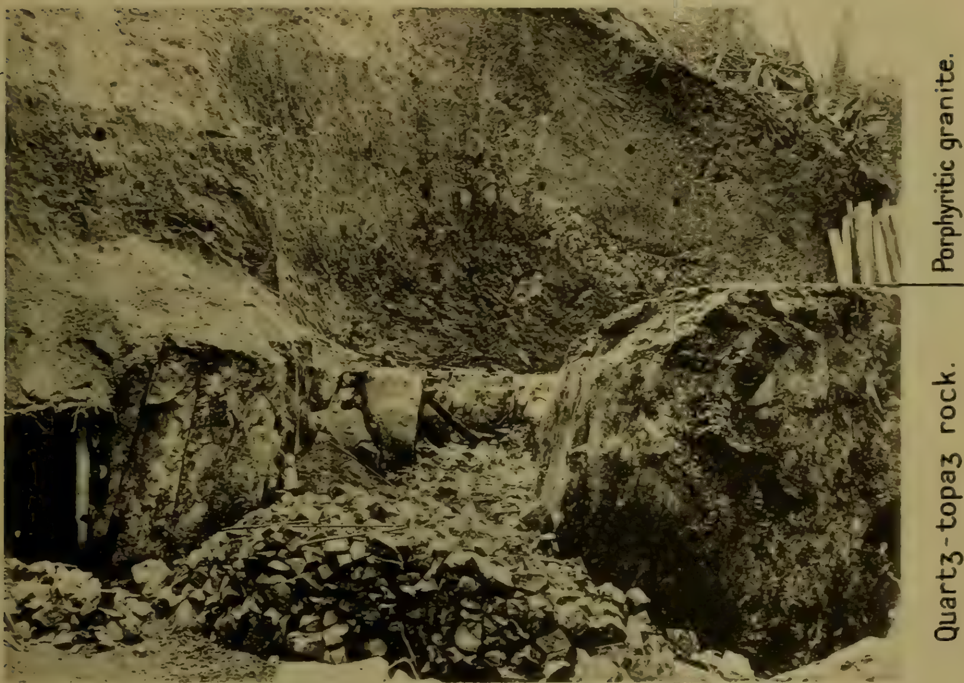


Fig. 2. Section in Quarry C, showing the 'Reaction Border' of Schorl-Rock.

J.B.S. Photo.

Bemrose, Collo., Derby

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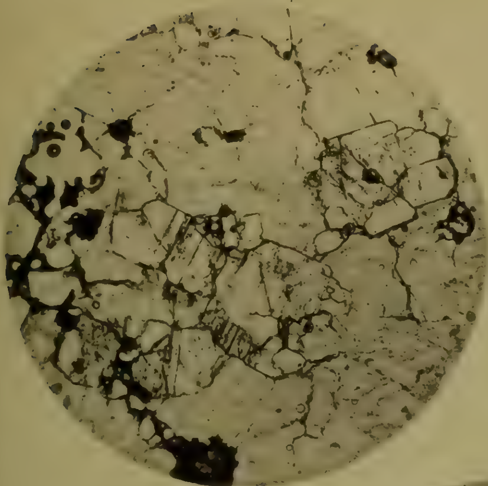

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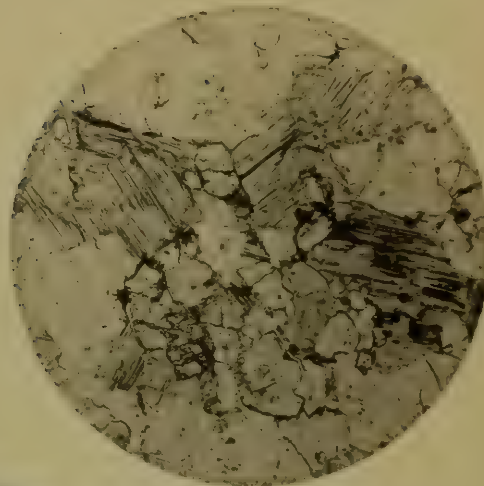

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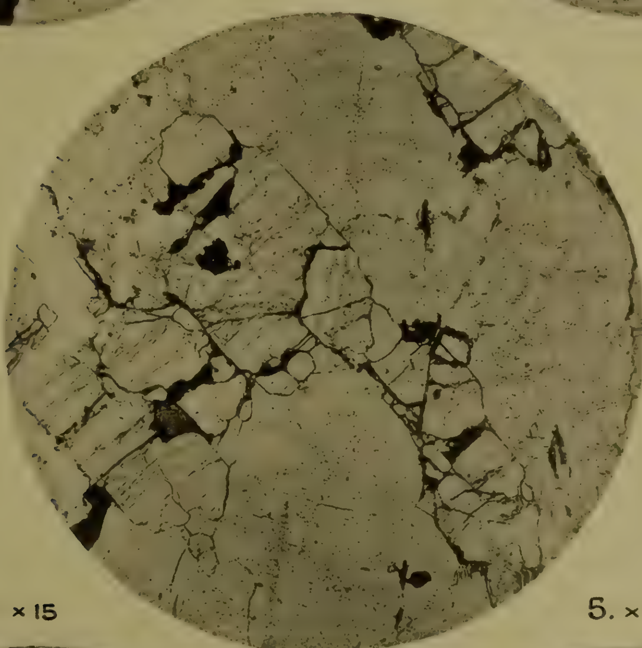

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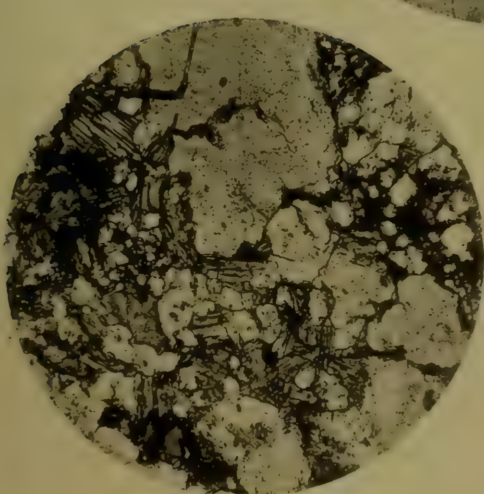

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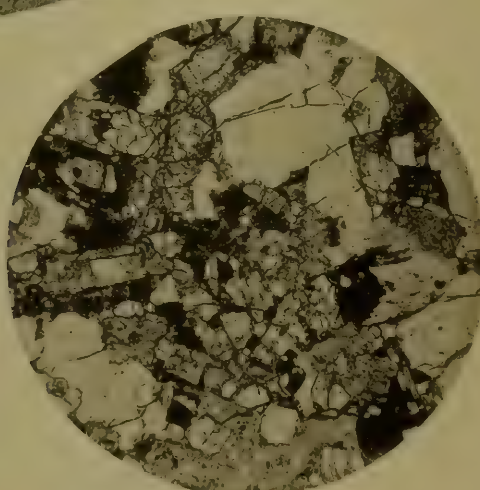

H. H. T. Photomicro.

Bemrose, Collo., Derby.

IGNEOUS ROCKS FROM GUNONG BAKAU.

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I am indebted to Dr. H. H. Thomas, Sec.G.S., for assistance in preparing the photomicrographs reproduced in Pl. LII.

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OF

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CONTENTS.

PAPERS READ.

[No. 280 of the Quarterly Journal will probably be published at the end of December.]

[The Editor of the Quarterly Journal is directed to make it known to the Public that the Authors alone are responsible for the facts and opinions contained in their respective Papers.]

*** The Council request that all communications intended for publication by the Society shall be clearly and legibly written on one side of the paper only, with proper references, and in all respects in fit condition for being at once placed in the Printer's hands. Unless this is done, it will be in the discretion of the Officers to return the communication to the Author for revision.

The Library at the Apartments of the Society is open every Weekday from Ten o'clock until Five, except during the fortnight commencing on the first Monday in September, when the Library is closed for the purpose of cleaning; the Library is also closed on Saturdays at One P.M. during the months of August and September. It is open until Eight P.M. on the Days of Meeting for the loan of books, and from Eight P.M. until the close of each Meeting for conversational purposes only.

Vol. LXX. DECEMBER, 1914. **No. 280.**
PART 4.

THE

QUARTERLY JOURNAL

OF THE

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EDITED BY

THE ASSISTANT-SECRETARY.

[With Two Plates, illustrating a Paper by
Prof. P. Marshall.]

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SESSION 1914–1915.

1915.

Wednesday,	April	14 —28*
,,	May	12*
,,	June	9 —23*

[*Business will commence at Eight o' Clock precisely.*]

The asterisks denote the dates on which the Council will meet.

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18. *The* SEQUENCE *of* LAVAS *at the* NORTH HEAD, OTAGO HARBOUR, DUNEDIN (NEW ZEALAND). By PATRICK MARSHALL, M.A., D.Sc., F.G.S., Professor of Geology in the University of Otago. (Read May 27th, 1914.)

[PLATES LIII & LIV.]

CONTENTS.

I. GENERAL GEOLOGY.

THE North Head of Otago Harbour is situated in lat. 45° 47′ 30″ S. and in 170° 45′ long. E. It is 13 miles distant from the city of Dunedin, in a north-easterly direction. The head is a precipitous cliff facing nearly due east in its southern portion; but, bending slightly westwards in its northern portion, it runs from south 15° east to north 15° west, and therefore in this portion faces 15° to the north of east.

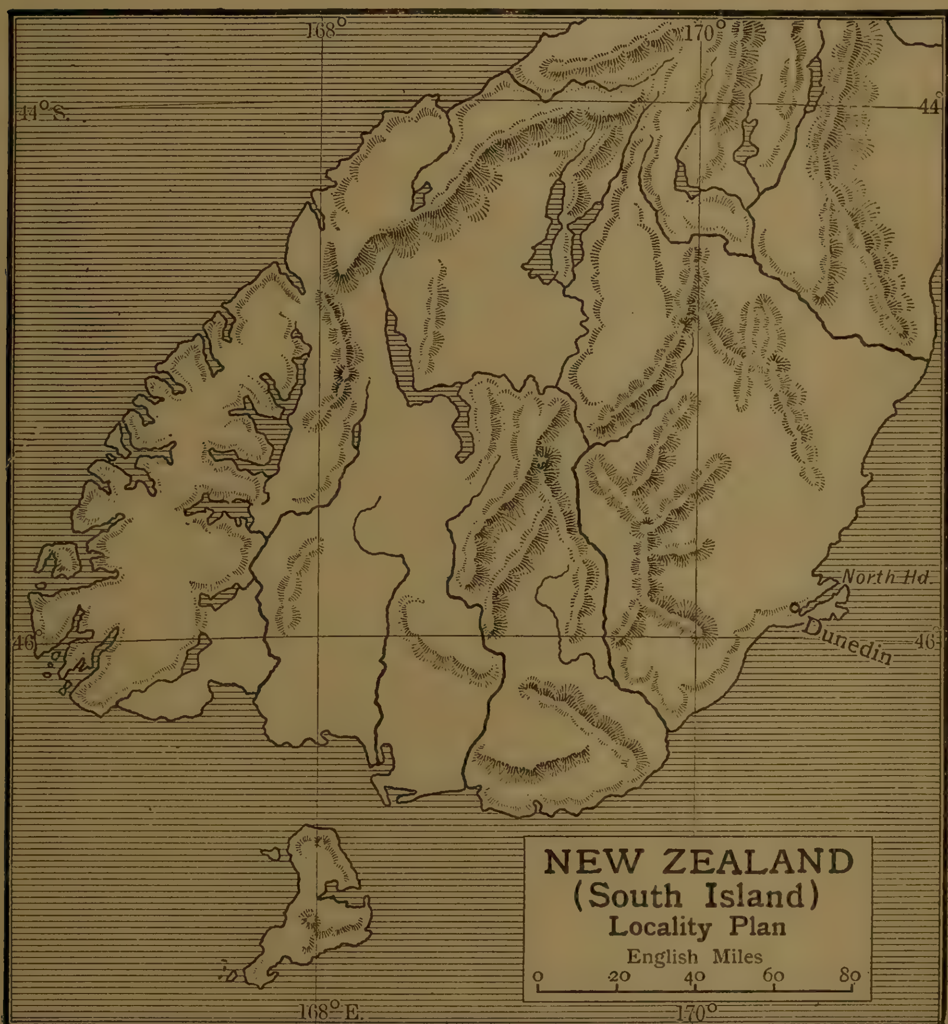
The cliff has an altitude of 530 feet at its highest point almost in the middle of the section, and throughout its length it is more than 300 feet high, except at the southern end, where it slopes somewhat gradually to the sand-hills which skirt its base. The lower part of the southern end of the cliff is partly obscured by scree-slopes and blown sand, and for 200 yards from its northern extremity the lower part of the cliff is hidden beneath an immense slip. Elsewhere, for a length of a mile and a half, the cliff presents a surface that is almost perpendicular, and it thus affords a remarkably clear section nearly bare of vegetation and quite free from all those difficulties of interpretation that are always associated with folding and faulting. This cliff was briefly mentioned in a previous paper of mine, published in the Quarterly Journal of this Society in 1906 (vol. lxii, p. 417). In this description the general nature of the succession was indicated. The lava-flows exposed in the clear section include a trachyte, three trachytoid phonolites, one kaiwekite, two trachydolerites, and numerous basalts. It is, therefore, evident that a complete examination of the different lavas might be expected to throw a considerable and perhaps important light upon the causes which promote those differences that are sometimes found in the succession of lavas that issue from a single volcano, or at least in the same volcanic district.

In the first place, evidence was sought with the object of ascertaining whether the various lavas which are exposed in the cliff

were the products of the activity of a single volcano. Some difficulty was experienced in coming to a conclusion on this point, since all the outward signs of volcanic action have now been destroyed by subaërial erosion, and therefore the surface-features that exist do not indicate the point from which the lavas were emitted.

Internal evidence also was sought in the dip of the various flows

Fig. 1.



of lava and in the extent to which they suffered from erosion during the intervals between the different periods of activity. The dip or slope of the lavas was found to be remarkably uniform. The amount of dip is 14·6°, and is directed 20° south of east. The rise is thus 1 in 4, a little to the north of west. This rise is in the direction of the high country (1600 feet) near Mihiwaka and Mopanui; but it is considerably steeper than the actual average rise of the country in the same direction.

2 D 2

In general, the thickness of each lava-flow is fairly constant. It is certainly constant enough to warrant the conclusion that all the different streams of lava flowed down the same slope, and presumably, therefore, they were emitted from the same orifice. In every case a scoria-bed of some thickness covers the lava. The material of the scoria is moderately coarse, as a rule, although that which overlies the lowest phonolite is much finer than the rest. The general coarseness necessarily indicates that the centre of volcanic activity was not far away from the section displayed, and this is true of all the different types of lava, except the trachydolerite No. 21, which, as will be shown later, does not extend over the length of the section. Only one distinct dyke is to be seen, and it is formed of basalt. This dyke is situated at that part of the cliff where the middle flow of phonolite rises to the summit, and it extends to the top of the cliff at this point.

The lava-flows appear to have suffered only to a slight extent from denudation, and, with the exception of the middle phonolite, the surface of each flow seems to have undergone very little denudation before the succeeding flow of lava covered it. Beneath the thick flow of basalt (21) is a boulder-bed, which, of course, varies greatly in thickness. It generally consists in the main of pebbles and boulders of phonolite, evidently derived from the middle flow (14): which flow, in the exposed section, is covered by six other intermediate flows of basalt. This appears to indicate that a considerable time elapsed between the outflow of basalts 20 & 21; though it must be allowed that on a volcanic slope each lava does not necessarily cover the whole surface, and at certain points where a particular lava-flow became heaped up it may not have been concealed until many succeeding lavas had issued.

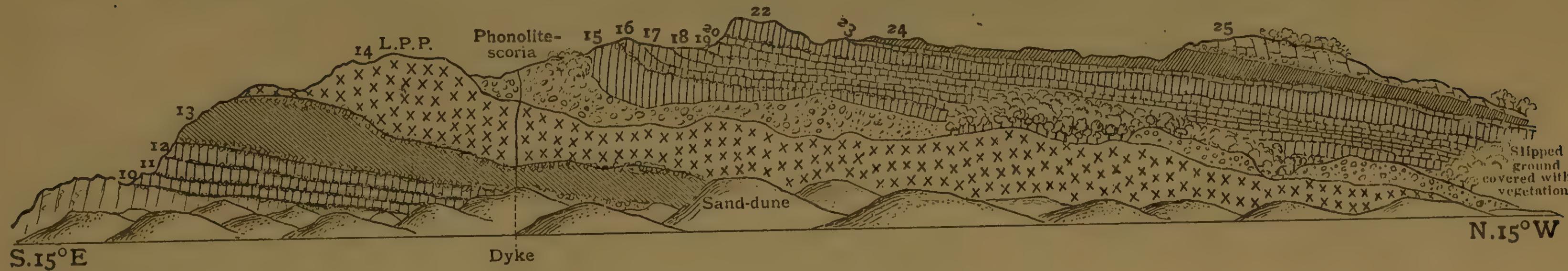
All these volcanic rocks are younger than the Miocene, for they rest upon sediments of this age near Dunedin.

A detailed examination of the cliff showed that no rock can actually be seen beneath the trachyte. The cliff at this point—in the extreme south—is low, at a considerable distance from the sea-beach, and is here covered with a growth of vegetation which to some extent obscures the section: consequently, it is difficult to form any certain conclusions about the relations of some of the rocks one to the other. It appears to me, however, that an error was made in my previous paper, in the statement that a flow of basalt occurs beneath the trachyte.[1]

Above the trachyte is a bed of tuff, varying from 10 to 60 feet in thickness. This is followed by a flow of phonolite, which is also of very variable thickness: at the southernmost exposure it is about 50 feet thick, and is divided in the middle by a bed of scoria 12 feet thick. Farther north, at the extreme left of fig. 2 (p. 385), where the section becomes continuous, there is but one flow of phonolite, and its thickness is only 10 feet. Above this phonolite is a conspicuous bed of white tuff 8 feet thick, but thinning out northwards. Upon this follow nine flows of

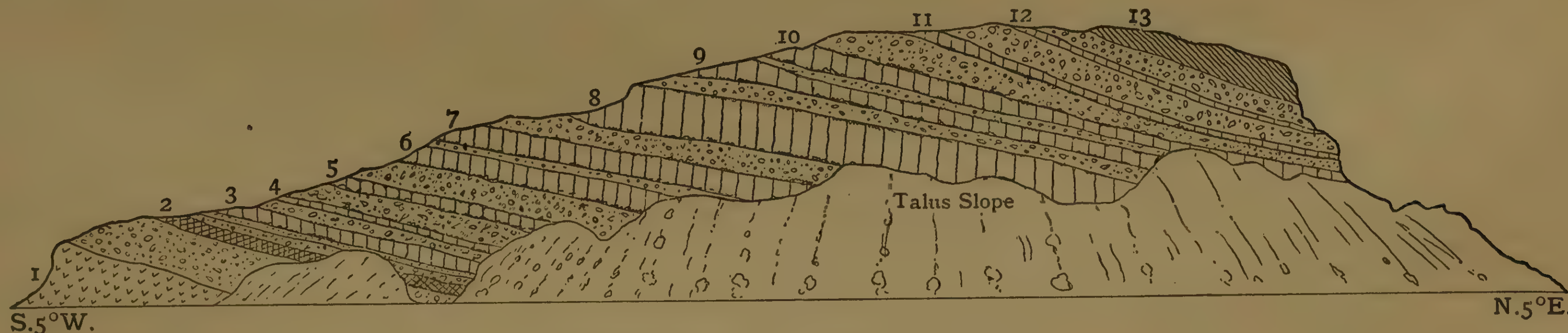
[1] Q. J. G. S. vol. lxii (1906) p. 418.

Figs. 2 & 3.—*Sections through the North Head, Otago Harbour, Dunedin (New Zealand).*



[Length = 1 mile and a quarter. Height = 540 feet.]

10-12 & 15-23 = Basalt-lavas ; 13 = Kaiwekite ; 14 = Logan's Point Phonolite ; 24 = Trachydolerite ; 25 = Upper trachytoid phonolite.



[Length = Half a mile. Height = 400 feet.]

1 = Trachyte ; 2 = Phonolite ; 3–12 = Basalts ; 13 = Kaiwekite.

basalt, each of these being separated from those above and below it by a bed of scoria, which is in nearly all cases thicker than the actual lava. The upper and lower surfaces of the lavas are highly irregular, and the thickness of each flow is extremely variable. The scoria is rather loose, much oxidized, and is in most cases dark red, thus indicating that the eruptions were subaërial.

Resting on the basalts is a flow of a peculiar lava about 30 feet thick, with somewhat regular horizontal joints. The rock is highly porphyritic, contains big crystals of hornblende and felspar, with smaller ones of augite, and is covered by a thick but very irregular scoria-bed. The porphyritic lava is followed by a thick flow of phonolite, of the type described in my previous paper as the Logan Point Phonolite (it contains much nepheline and cossyrite). Scoria again covers the phonolite to a depth of 50 feet on the average.

There is then another succession of basalt-flows, this time eight in number, and, as before, relatively thin and separated by thick red beds of scoria. The lowest of these basalts is a bigger flow than the rest, with the exception of the seventh, which is also of great size. In my previous paper on this section I represented a trachydolerite, then called a basanite-lava, as situated below this large flow of basalt. More careful observation, however, showed that the trachydolerite does not occur in the actual face of the cliff, although it is present beneath this identical basalt a little farther north at Hayward's Point. It is, therefore, correct to place the trachydolerite at this place in the series of lavas, for it is obviously absurd to suppose that each of the lavas that issue from a volcano would flow over all parts of the slopes of the mountain. It is, in fact, probable that the series of lavas shown in the face of the cliff by no means represents the complete succession of lavas that issued from the volcano, although the series certainly does represent the nature of the lava that was emitted at successive periods of the activity of the volcano.

Two flows of basalt follow the trachydolerite, and then occurs another porphyritic rock, which in some respects resembles the earlier one. As before, this porphyritic type is succeeded by a phonolite, which this time contains no cossyrite and very little nepheline; while porphyritic crystals of felspar impart to it a less dense appearance than that of the other flows of phonolite.

The actual succession of the lavas is as follows, from above downwards:—

	Thickness in feet.
25. Trachytoid phonolite	40
Tuff	15
24. Trachydolerite	20
Tuff	6
23. Basalt	5
Tuff	8
22. Basalt	40
Conglomerate	2
Tuff	6

		Thickness in feet.
21. Trachydolerite as shown 400 yards west		30
20. Basalt		6
	Tuff	10
19. Basalt		5
	Tuff	8
18. Basalt		4
	Tuff	9
17. Basalt		7
	Tuff	8
16. Basalt		5
	Tuff	12
15. Basalt		25
	Tuff	50
14. 'Logan's Point' Phonolite		120
	Tuff	10
13. Kaiwekite		30
	Tuff	20
12. Basalt		8
	Tuff	20
11. Basalt		6
	Tuff	18
10. Basalt		10
	Tuff	4
9. Basalt		10
	Tuff	10
8. Basalt		20
	Tuff	15
7. Basalt		14
	Tuff	6
6. Basalt		9
	Tuff	15
5. Basalt		5
	Tuff	10
4. Basalt		3
	Tuff	10
3. Basalt		10
	Tuff	8
2. Phonolite		20
	Tuff	60
1. Trachyte		30

In this series the lavas have a total thickness of 422 feet, and of this the basalts are represented by 192 feet, the phonolites by 180 feet, and the porphyritic rock (which is of the same nature as the kaiwekite of my former paper) accounts for a thickness of 50 feet of rock only. As already stated, the amount of the rocks in the section cannot reasonably be taken as an indication of the relative quantity of the different types of lava that actually issued from the crater of the volcano, for the section is merely composed of those lavas that happened to flow down one of the sides of the cone. It does, however, appear that the basic lavas are in this instance much thinner than those that have a more acid and alkaline character. In all cases the great thickness of the tuffs and scorias clearly indicates that the orifice from which the lavas issued was comparatively close to the locality where the section is exposed.

II. Petrography.

Since the series of lavas is shown so clearly that there can be no doubt whatever of the order of emission, it has been considered advisable to give a brief description of the petrographical characters of every member of the series. In these descriptions the relative quantities of the different minerals in the rocks have been gauged by Rosiwal's method.

(25) Highest phonolite.—A few irregular, partly corroded crystals of anorthoclase with many minute inclusions of ægirine-augite. The crystals measure 4 × 2 mm. Rarely idiomorphic crystals of ægirine-augite measuring ·8 × ·15 mm. occur.

Ground-mass: irregular anorthoclase-microlites form about 70 per cent. of the total, and allotriomorphic grains of ægirine-augite about 20 per cent. There is a small quantity of allotriomorphic nepheline.

(24) Trachydolerite (called 'St. Leonard's Phonolite' by me in 1906).—Occasional phenocrysts of hornblende, sometimes very large, but usually measuring 3 × 1·5 mm., and always having a resorption-border of varying thickness. Strongly pleochroic; α pale yellow, β dark reddish-brown, γ dark yellow-brown. The hornblende often includes small augites. Augite-phenocrysts pale pink, 3 × 1 mm., often with inclusions of the ground-mass and of large magnetites. Slightly pleochroic. Occasionally the augite has grown round the hornblende, but in such cases it has a greenish tint. Both the augite and the hornblende are twinned somewhat rarely. Felspar-phenocrysts are common, mainly oligoclase, but there is some anorthoclase.

Ground-mass: felspar-laths with a rough parallel arrangement, ·15 × ·008 mm., of simply-twinned oligoclase constitute 68 per cent.; augite 32, and magnetite 5 per cent of the whole.

(23) Basalt.—Some glomeroporphyritic patches 3 mm. in diameter, mainly oligoclase with a little brownish-green augite. A few crystals of anorthoclase, much corroded; olivine-grains few, corroded, generally stained with limonite, ·5 mm. in diameter. Augite-crystals measuring 1·5 × ·5 mm., idiomorphic, pale brown, faintly pleochroic. In one crystal good hour-glass structure is shown.

Ground-mass: labradorite measuring ·3 × ·05 mm., including capillary microlites of augite; olivine infrequent, in rounded grains stained with limonite; augite idiomorphic, pale green, ·01 × ·006 mm.; magnetite abundant.

(22). Basalt.—Labradorite-phenocrysts fairly abundant, 2 × ·7 mm.; brown augite, pleochroic, 5 × 3 mm.; a few rounded olivines, ·5 mm.

Ground-mass: indistinct flow-structure; labradorite, ·15 × ·03 mm., 57 per cent.; pale-green augite, ·02 × ·008 mm., 34 per cent.; magnetite, ·01 mm., 9 per cent.

(21) Trachydolerite (called 'basanite' by me in 1906).—Large phenocrysts of nepheline and of sodalite are fairly abundant, and the rock thus has a coarse porphyritic habit. These crystals are surrounded by a zone of secondary minerals, chiefly calcite and natrolite. Small crystals of ægirine measuring in longest diameter ·3 mm. Some grains of olivine, ·7 mm. in diameter, altered into serpentine and calcite.

Ground-mass very fine-grained. Microlites of ægirine-augite form the most striking constituent. They contain grains of magnetite, and in many instances when they are irregular in shape they have been clearly derived from the resorption of hornblende. The clear mineral has no definite form, and is for the most part nepheline, though a few microlites of felspar can be distinguished. A considerable quantity of magnetite occurs in minute grains. Occasional crystals of brown apatite. Nepheline 40 per cent.; felspar 16 per cent.; ægirine-augite 37 per cent.; magnetite 7 per cent.

(20) Basalt.—Labradorite-phenocrysts fairly abundant, $2 \times \cdot 7$ mm.; augite brown and slightly pleochroic, 5×3 mm.; a few rounded olivines, ·5 mm.

Ground-mass: indistinct flow-structure; labradorite, $\cdot 15 \times \cdot 03$ mm., 62 per cent.; pale-green augite, $\cdot 02 \times \cdot 005$ mm., 31 per cent.; magnetite, ·01 mm., 7 per cent.

(19) Basalt.—Small glomeroporphyritic patch of felspar and greenish augite, but no true phenocrysts.

Ground-mass: labradorite-laths, $\cdot 3 \times \cdot 03$ mm., 55 per cent.; augite, $\cdot 8 \times \cdot 03$ mm., 45 per cent.; magnetite, ·04 mm., 10 per cent.; a very few small olivines.

(18) Basalt.—Large patch of labradorite-crystals, 5 mm.; also single crystals, $1 \cdot 5 \times \cdot 5$ mm. One large crystal of anorthoclase, 2·5 mm.; pale brownish-green augite, twinned, not pleochroic, $\cdot 1 \times \cdot 05$ mm.; olivine, $1 \times \cdot 05$ mm.

Ground-mass: labradorite, $\cdot 08 \times \cdot 02$ mm., 67 per cent.; pale-green augite-microlites, $\cdot 05 \times \cdot 02$ mm., 19 per cent.; olivine rounded, ·05 mm., 4 per cent.; magnetite ·02 mm., 10 per cent.

(17) Basalt.—Glomeroporphyritic aggregates of acid labradorite, 6 mm. Corroded crystals of anorthoclase, $2 \times \cdot 3$ mm. Brownish-green pleochroic augite, poorly zoned: includes small pieces of olivine, sometimes twinned. Olivine small, infrequent.

Ground-mass: acid labradorite, $\cdot 08 \times \cdot 02$ mm., 70 per cent.; pale-green augite-microlites, $\cdot 05 \times \cdot 02$ mm., 16 per cent.; olivine, ·03 mm., 4 per cent.; magnetite, ·02 mm., 10 per cent.

(16) Basalt.—Phenocrysts of labradorite, $3 \cdot 5 \times 1 \cdot 5$ mm., containing many inclusions of magnetite and of augite, in which the hour-glass structure can be seen; greenish-brown augite, showing very distinct zonal structure. Very little olivine.

Ground-mass: labradorite, $\cdot 4 \times \cdot 04$ mm., 42 per cent.; augite,

pale-green microlites, ·04 × ·01 mm., 39 per cent.; magnetite, ·025 mm., 14 per cent.

(15) Basalt.—There is a patch of oligoclase-crystals 5 mm. in diameter; augite-crystals rather infrequent; olivine practically absent.

Ground-mass: microlites of oligoclase-andesine constitute 55 per cent.: they measure ·4 × ·07 mm. Pale-green granular augite, ·04 × ·012 mm., forms 34 per cent., and magnetite-crystals, ·012 in diameter, make up the balance of 11 per cent. There is a considerable quantity of bright-green serpentine and a small quantity of a reddish-brown, strongly pleochroic hornblende, which occurs interstitially, and may be original.

(14) Phonolite.—No phenocrysts. Felspar and nepheline appear to be present in about equal quantity. The felspar is sanidine in rather small microlites, ·2 × ·03 mm. The nepheline occurs in small rectangles, and is quite fresh. Each of these minerals constitutes about 25 per cent. of the rock. Ægirine-augite of a granular nature forms 24 per cent., and cossyrite the remaining 18 per cent. There is a little magnetite and apatite. The cossyrite occurs in mossy growths.

(13) Kaiwekite.—Large crystals of anorthoclase measuring 5 × 2 mm. are fairly numerous. They are usually corroded, and contain a large number of inclusions, mostly ægirine. Augite-crystals are mostly of the violet titaniferous variety, showing distinct pleochroism. Usually they have a greenish border of ægirine-augite, which contains a large quantity of magnetite. In the case of one crystal 1 mm. wide the green border is ·08 mm. wide. Hornblende in hand-specimens very large, but in sections only small crystals have been intersected. It is a dark-brown variety, probably barkevikite, has a wide resorption-border, and occasionally encloses purple augite. Olivine rather frequent, 1 × ·5 mm., and very much corroded.

Ground-mass: small microlites of felspar (probably oligoclase) constitute about 80 per cent. They measure ·02 × ·001 mm. Small, short augite-crystals of irregular size make up 15 per cent., and the remaining 5 per cent. consists of magnetite. Short broad crystals of brown augite are common.

(12) Basalt.—Phenocrysts of acid labradorite are common, measuring 1·5 × 1 mm. Augite-crystals infrequent, brown, 1·7 × 1·2 mm. Olivine scarce, ·3 mm.

Ground-mass: acid labradorite, ·2 × ·04 mm., 55 per cent.; pale-green augite, ·08 × ·02 mm., 28 per cent.; magnetite ·02 mm., 17 per cent.

(11) Basalt.—Felspar-phenocrysts of labradorite small, 1·5 × 1 mm. Augite-crystals much larger than those of the other

minerals, but infrequent, 1·7 × 1·2 mm. Olivine rather frequent, idiomorphic, 1 mm.

Ground-mass: labradorite-microlites, ·1 × ·01 mm., 6 per cent.; pale-green augite, ·08 × ·04 mm., 25 per cent.; magnetite, ·04 mm., 5 per cent.

(10) Basalt.—Phenocrysts of labradorite, few, ·5 × 1 mm.; augite more abundant, brown, 1 × 1 mm.; olivine, sometimes idiomorphic, 1 × ·8 mm.

Ground-mass: acid labradorite, ·15 × ·08 mm., 57 per cent.; pale-green augite, ·04 × ·01 mm., 28 per cent.; magnetite, ·032 mm., 15 per cent.

(9) Basalt.—Labradorite-phenocrysts not numerous, small, 1 × ·05 mm.; augite, a few brown crystals, 1 × ·5 mm.; olivine serpentinized, in round grains measuring ·5 mm. in diameter.

Ground-mass: labradorite, ·3 × ·03 mm., 54 per cent.; augite, ·03 × ·05 mm., 33 per cent.; magnetite, ·05 mm., 13 per cent. A few crystals of brown apatite.

(8) Basalt.—Phenocrysts few, mainly labradorite, ·8 × ·4 mm.

Ground-mass: labradorite, ·16 × ·02 mm., 47 per cent.; augite very pale green, rounded or short crystals, ·01 × ·006 mm., 35 per cent.; magnetite ·004 mm., 14 per cent.; some rounded grains of olivine, 5 per cent.

(7) Basalt.—No phenocrysts.

Ground-mass: labradorite, ·3 × ·02 mm., 48 per cent.; pale-green augite, ·025 × ·006 mm., 36 per cent.; magnetite, ·006 mm., 16 per cent.; olivine idiomorphic, rather sparingly present.

(6) Basalt.—Felspar-phenocrysts almost absent; augite frequent, 3 × 2 mm., well zoned, sometimes exhibiting hour-glass structure and twinned; olivine abundant, 2 × 1 mm.

Ground-mass: labradorite-laths ·12 × ·02 mm., 60 per cent.; pale-green augite, ·08 × ·01 mm., ·15 per cent.; olivine, rounded grains, ·04 mm., 10 per cent.; magnetite, ·04 mm., 15 per cent.

(5) Basalt. — Phenocrysts of oligoclase and anorthoclase, ·4 × 3 mm.; augite brown, with occasionally a greenish centre, 3 × 1 mm.—a tendency to hour-glass structure is fairly frequent; olivine very scarce and in small grains, ·2 mm.; perofskite occurs in distinct crystals, measuring ·1 mm.

Ground-mass: acid-labradorite, ·8 × ·005 mm., 68 per cent.; pale-green augite, ·04 × ·008 mm., 21 per cent.; magnetite and perofskite, ·008 mm., 11 per cent.

(4) Basalt.—Felspar-phenocrysts, apparently belonging to anorthoclase, oligoclase, and labradorite, ·5 × 2 mm.; brown augite, slightly pleochroic, sometimes twinned, 1 × ·5 mm.; olivine roundish, much oxidized, 1 mm.

Ground-mass: labradorite-microlites measuring ·13 × ·015 mm., 76 per cent.; augite, ·12 × ·02 mm., 10 per cent.; magnetite, ·012 mm., 14 per cent.

(3) Basalt.—Anorthoclase-phenocrysts, 5 mm. long, with much included matter, especially augite, which may be in micrographic intergrowth, and some oligoclase, which may be zoned; augite greenish, especially in the centre, slightly violet, with some pleochroism, sharply idiomorphic, 1 mm. long, but not abundant; olivine-grains, usually rounded, 1 mm. in diameter, not abundant.

Ground-mass: labradorite-microlites measuring ·2 × ·02 mm., 62 per cent.; augite, ·008 × ·001 mm., 29 per cent.; magnetite, ·008 mm., 9 per cent.

(2) Phonolite.—No phenocrysts; sanidine-microlites, ·2 × ·01 mm., 64 per cent.; ægirine-augite, 43° extinction, ·26 × ·02 mm., 21 per cent.; magnetite, ·02 × ·05 mm., 5 per cent. The structure of the microlites of sanidine and ægirine-augite is interwoven.

(1) Trachyte.—Anorthoclase-phenocrysts, abundant, 5 mm. long.

Ground-mass almost solely composed of anorthoclase-microlites, ·26 × ·06 mm.; a little magnetite. Structure trachytoid.

Summary of Petrographical Features.

These short descriptions of the structure and the mineral composition of the rocks of this series may be briefly summarized as follows:—

The lowest lava is entirely composed of anorthoclase. It is succeeded by a phonolite in which sanidine is the predominant mineral, although ægirine-augite and magnetite attain some importance. A series of basalts follows. The lower of these contain conspicuous, much-corroded xenocrysts of anorthoclase. The fifth of these basalts (No. 6) is especially basic, and in particular contains much more olivine than any other rock in the whole series.

This series of ten basalts is succeeded by a lava of a wholly different type, belonging to the class that I have previously termed kaiwekite (No. 13). It has a coarsely porphyritic structure, and hornblende of a barkevikitic type forms the largest crystals in it. The crystals of this mineral are deeply resorbed, and were evidently formed under conditions that were wholly different from those under which extrusion of the lava took place. The augite, too, is widely different from that of the basalts, for it has distinctly the violet tinge associated with the presence of titanium; while it shows at times a small border of ægirine. The felspar-phenocrysts also include anorthoclase as well as labradorite.

There is a sudden transition from this to the next lava, which contains no phenocrysts, while the minerals of the ground-mass are

nearly all different from those of the previous lava. The felspar is sanidine, the pyroxene is ægirine, the amphibole is cossyrite, and there is also an abundance of nepheline.

There is again a succession of several basalts, the lowest of which is, however, distinctly less basic than the rest. After six basalt-flows another complete change recurs, and a trachydolerite is encountered. In this are large phenocrysts of nepheline and sodalite, and very little felspar, which is entirely restricted to the ground-mass. There is much indication of the former presence of hornblende, which has been entirely resorbed, and the pyroxene is ægirine-augite.

Again, there are two more basalts, one of which is an exceptionally large flow, and a trachydolerite is then again found. In this rock there is a little anorthoclase and an abundance of small crystals of barkevikite, although they still show conspicuous resorption and have the same intimate relation with the violet-tinted pyroxene. Finally, there is another phonolite, but in this case it contains a few crystals of anorthoclase.

The order of succession, which is so conspicuous here, is found to be not infrequent elsewhere in the neighbourhood. Thus, on the west side of Wickliffe Bay, at the See House and at Long Beach, there is a similar succession from an intermediate rock, with very large crystals of hornblende, followed by a dense phonolite and afterwards by a basalt.

III. Chemical Composition.

The actual composition of each of the rocks is shown in the accompanying table (pp. 394–95). The following statement emphasizes those points that appear to call for special notice.

The lowest rock, a trachyte, is practically wanting in lime and magnesia, and contains little iron. The second lava, a phonolite, shows a distinct advance in those constituents, but is still somewhat deficient in them. The basalts, as a whole, are low in magnesia and above the average in alkalies, though No. 6 is an exception and is distinctly the most basic rock of the whole series. In the kaiwekite (No. 13) the alkalies advance very distinctly, with a corresponding increase in silica and decrease in lime and magnesia. These features are still more marked in the succeeding phonolite—in fact, chemically the kaiwekite is simply a connecting-link between the basalts and the phonolite. This phonolite is the most alkaline rock of the whole series.

The basalt (No. 15) which succeeds the phonolite is distinctly less basic than the rest of the basalts, and in some measure marks a transition between the alkaline and the basic rocks. The rest of the basalts are, as a whole, a little higher in alumina and lower in lime than those that lie beneath the middle phonolite.

The trachydolerite (No. 21) is comparable with the kaiwekite, although the soda and alumina are somewhat higher and the silica distinctly lower, as would be expected from the presence of

CHEMICAL COMPOSITION OF THE LAVAS OF

	(1) Trachyte.	(2) Phonolite.	(3) Basalt.	(4) Basalt.	(5) Basalt.	(6) Basalt.	(7) Basalt.	(8) Basalt.	(9) Basalt.	(10) Basalt.	(11) Basalt.	(12) Basalt.
SiO_2	65·34	59·54	49·10	48·10	49·10	45·05	48·31	49·06	46·91	46·74	46·84	48·67
TiO_2	0·12	0·38	2·16	2·36	2·03	2·53	2·43	2·57	3·58	3·44	2·33	2·44
Al_2O_3	18·56	19·04	14·30	16·03	16·08	13·01	15·17	15·24	15·25	13·28	17·04	16·09
Fe_2O_3	1·28	4·72	5·78	7·96	5·14	7·64	6·39	5·34	6·42	7·68	6·21	3·92
FeO	0·92	2·48	9·52	10·10	9·64	8·37	8·63	9·70	8·36	10·77	9·64	9·76
MgO	...	0·31	4·35	2·36	3·04	8·20	2·87	2·52	4·45	3·55	3·25	4·67
CaO	1·20	2·68	9·35	7·33	9·19	10·71	9·82	10·20	10·40	9·57	10·35	9·30
K_2O	5·58	4·17	1·73	1·14	1·64	1·77	2·60	1·54	1·25	1·10	0·46	1·06
Na_2O	6·79	6·25	3·41	4·35	3·85	2·34	3·18	3·42	3·13	3·55	3·67	3·58
P_2O_5	0·21	0·43	0·30	0·27	0·29	0·38	0·60	0·41	0·25	0·32	0·21	0·51
Totals...	100	100	100	100	100	100	100	100	100	100	100	100
These analyses have been recalculated to 100 after subtraction of the disturbing factor when comparing these analyses. The loss												
	1·20	4·68	4·00	6·02	5·21	4·00	4·20	5·38	5·32	6·72	5·42	6·61

abundant nepheline in such a rock. The two succeeding basalts exhibit no marked characteristics, and No. 24 is, again, a rock that chemically, at least, is a connecting-link and may perhaps be best called a trachydolerite, as it is much higher in alumina and lower in silica than the kaiwekite (No. 13). The final phonolite is comparable with No. 2, and like it is distinctly less alkaline than No. 14, which contains a large quantity of nepheline and ænigmatite.

In order to facilitate a comparison between the different rocks, two curves have been prepared (Pls. LIII & LIV). In both of these the abscissæ merely indicate the position of the rock in the series of lavas. In Pl. LIII the ordinates represent the molecular proportions in which the various constituents are present in the rocks. The diagram brings into prominence these two facts:—

(1) The fourfold alkaline development in the series, and (2) the conspicuous extent to which Nos. 13 and 24 are intermediate between the phonolites and basalts in composition.

THE NORTH HEAD, OTAGO HARBOUR.

(13) Kaiwekite.	(14) Phonolite.	(15) Basalt.	(16) Basalt.	(17) Basalt.	(18) Basalt.	(19) Basalt.	(20) Basalt.	(21) Trachydolerite.	(22) Basalt.	(23) Basalt.	(24) Trachydolerite.	(25) Phonolite.
57·22	59·00	50·88	48·60	48·37	47·67	48·77	49·95	51·57	47·37	47·67	51·15	57·60
1·26	0·41	1·68	2·23	1·98	2·16	1·85	1·88	1·49	2·20	2·08	0·42	0·55
15·23	17·09	16·75	17·90	18·73	17·53	17·44	16·42	18·30	17·41	17·52	20·80	20·78
4·32	5·30	6·67	7·12	6·01	7·24	5·40	5·46	2·10	3·24	7·45	5·95	4·00
4·62	3·25	7·74	8·00	6·82	7·89	7·34	8·74	7·04	11·22	7·42	5·54	3·50
2·20	0·21	1·34	2·27	3·36	3·45	3·23	3·19	2·43	3·74	3·38	1·95	0·35
5·89	1·46	7·52	7·54	8·48	8·40	9·42	7·60	5·84	10·80	9·43	5·60	1·98
3·39	5·39	2·60	1·90	2·50	1·35	2·55	2·55	3·75	1·26	0·77	2·87	4·67
5·60	7·47	4·47	4·14	3·38	3·94	3·54	3·83	7·14	2·52	3·90	5·22	6·05
0·27	0·42	0·35	0·30	0·37	0·37	0·46	0·38	0·34	0·24	0·38	0·50	0·52
100	100	100	100	100	100	100	100	100	100	100	100	100

water, as its amount, owing to hydration and serpentinization, was a on ignition of dry powder of each rock is shown below.

3·78	2·32	3·60	4·21	4·84	3·96	4·96	4·00	4·40	4·43	6·20	2·72	2·60

Pl. LIV shows the proportions of the amounts of the various oxides contained in the rocks to that of silica, reduced to percentages of the amount of silica. This mainly accentuates the curves plotted in the previous diagram (Pl. LIII). In both of these the analyses have been recalculated to a total of 100, after the amount of water had been subtracted from the sum.

All the analyses were calculated according to the chemico-mineralogical scheme of American authors. This classification, however, does not appear to throw any fresh light on the relationships of the various rocks. The basalts, in particular, are very near the boundary between Class II and Class III. Nearly all the basalts in the lower part of the series belong to the auvergnose subrang, while those in the upper half for the most part belong to the hessose. Nos. 13, 15, and 24 are andose, while the phonolites 14 and 25 are essexose.

IV. Classification of the Rocks.

The great majority of these rocks fall readily into well-known and generally recognized groups. Thus the lowest rock is a trachyte, obviously an effusive representative of the bostonites. A similar rock from Portobello in this district has been described in the following words by Rosenbusch:

'Ein reiner Sanidintrachyt ohne femische Gemengtheile mit Einsprenglingen von Sanidin in trachytischer Grundmasse aus Sanidinleistchen.'[1]

In every case in which an analysis of this rock has been made there is so high a percentage of soda, that the felspar can hardly be anything else than anorthoclase, or, at any rate, soda-orthoclase—a conclusion which is supported by the microscopical examination of my preparations.

Two of the phonolites (No. 2 & No. 25) belong distinctly to the trachytoid type, and contain very little nepheline. The third, No. 14, has a considerable quantity of nepheline, and is almost nephelinitoid in structure.

The basalts, too, call for no special remarks, except that they occasionally have some anorthoclase-crystals, which are in all cases much corroded.

The three lavas, of which No. 13 is classed as a kaiwekite and the other two (No. 21 & No. 24) are classed as trachydolerites, demand special consideration. The name kaiwekite was first used by me in 1906.[2] The characters there stated for that type of rock are the following:—

(1) The abundance of anorthoclase and of various felspathic intergrowths. (2) The very frequent square and isometric sections of felspar in the ground-mass. (3) The comparative absence of coloured rock-forming minerals. (4) The frequent occurrence of pyroxene, with a brown centre and an ægirine margin, and of serpentine-pseudomorphs after olivine.

On the same page it is also stated that the late Prof. Rosenbusch, after kindly examining sections of the rock, informed me (*in litt.*) that the rock is mineralogically the equivalent of the rhomb-porphyries, and is the volcanic representative of the plutonic laurvikites. The rock here classed as kaiwekite has rather more coloured constituents than the specimens seen by Rosenbusch, but the chemical composition of the rock is so closely similar to that of laurvikite that the suggestion made by him must be adopted. Kaiwekite is included by him among the pantelleritic trachytes. Another slightly more basic type is said to lie between the Ponza and the Drachenfels types of trachyte.[3]

An actual specimen of No. 24, and another rock allied to it, found in the Leith Valley, Dunedin, and previously classed by me as andesite,[4] was by Rosenbusch stated in MS. to be a

[1] 'Mikroskopische Physiogarphie der Mineralien & Gesteine: vol. ii, Massige Gesteine' 4th ed. (1908) pt. 2, p. 927.

[2] Q. J. G. S. vol. lxii (1906) p. 400 & pl. xxxix, fig. 2.

[3] H. Rosenbusch, *loc. supra cit.*

[4] Q. J. G. S. vol. lxii (1906) p. 408.

trachydolerite of the Siebengebirge type. The following analyses enable us to make a comparison between these rocks and other related types :—

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.
SiO_2	56·85	54·48	50·50	49·46	49·20	51·86	53·12	59·22
TiO_2	...	1·20	1·91	0·40	1·42	...	0·25	...
Al_2O_3	21·56	14·71	17·64	20·46	17·40	19·87	20·48	13·59
Fe_2O_3	3·44	5·68	5·41	5·72	2·00	6·30	5·13	5·55
FeO	1·14	3·02	4·02	4·62	6·69	3·11	1·50	4·03
MgO	0·85	2·10	3·33	1·68	2·31	2·33	1·88	1·66
CaO	5·26	5·60	7·91	5·40	5·55	3·77	4·29	5·13
Na_2O	6·07	6·13	5·52	5·81	6·78	6·20	6·20	5·31
K_2O	3·66	3·28	3·02	2·76	3·56	4·88	4·88	4·64
Loss on ignition	0·52	3·78	0·45	2·72	4·40	1·99	2·25	1·25
Totals....	99·35	99·98	99·71	99·03	99·31	100·31	99·98	100·38

I. Laurvikite. Tönsberg (Norway). H. Rosenbusch, 'Elemente der Gesteinslehre' 2nd ed. (1901) p. 114. No. 11.
II. Kaiwekite. Otago North Head, Dunedin (N.Z.). No. 13.
III. Essexite. Rongstock (Bohemia). H. Rosenbusch, *op. cit.* p. 177. No. 3.
IV. Trachydolerite. Otago North Head, Dunedin (N.Z.). No. 24.
V. Trachydolerite. Otago North Head, Dunedin (N.Z.). No. 21.
VI. Trachydolerite. Leith Valley, Dunedin (N.Z.). Q. J. G. S. vol. lxii (1906) p. 407
VII. Trachydolerite. Bauza (Spain). H. Rosenbusch, 'Elemente der Gesteinslehre' 2nd ed. (1901) p. 355. No. 3 *a*.
VIII. Andesite. Siebengebirge. H. Rosenbusch, *ibid.* p. 306. No. 5.

The relation of No. 13 to the laurvikite is quite marked, except in the low percentage of alumina, which is explained by the greater abundance of femic minerals. The kaiwekite in this series is richer in these substances than the St. Leonard's rock that was submitted to Rosenbusch.

No. 21 & No. 24, on the other hand, are undoubtedly trachydolerites, although the mineralogical differences between them are considerable. These differences are partly due to the complete resorption of the hornblende in No. 21. The relatively high percentage of the alkalies in that rock accounts for the minerals nepheline and sodalite, which are absent from No. 24. On the other hand, there does not seem to be any close relation between the trachydolerites and the Siebengebirge andesites, as suggested by Rosenbusch. The close relation between these trachydolerites and those of the Leith Valley, previously described, and also that of Bauza, is clearly shown. That the trachydolerites are the volcanic representatives of the essexites is shown by Analysis III. As previously stated, the presence of barkevikite, violet augite, and olivine, and the association of anorthoclase with a soda-lime felspar, strongly support this conclusion. There is also in the Dunedin district

every connecting-link between the kaiwekites and the trachydolerites: that is, between the volcanic representatives of the laurvikites and the essexites respectively.

Elsewhere along this south-eastern coast of New Zealand volcanic rocks in many places traverse the Tertiary rocks and the schists. All of these appear to be basalts of a more or less uniform type, and similar to the basalts of the Dunedin district. At Kakanui, 80 miles distant from Dunedin, there is a coarse submarine tuff, which contains large crystals of hornblende, and an acid oligoclase, as well as other minerals and fragments of peridotites. These have been described by Dr. J. Allan Thomson.[1]

V. Origin of the Different Lavas.

A consideration of the chemical and mineralogical characters of this sequence of lavas, as described, suggests that at least four different explanations might be advanced to explain its features:—

(1) A separate magmatic origin might be assigned to each of the lavas.
(2) Two magmas might be supposed to exist side by side, and their zone of contact might give rise to the mixed type.
(3) Attempts might be made to explain the whole series as a result of the differentiation of one parent magma. The different types would then be explained on the hypothesis that effusion would take place from different parts of the magma as it gradually cooled and various parts of it acquired the composition that characterizes the lavas which issued from it.
(4) The intermediate types, that is, the kaiwekite and the trachydolerites, may be regarded as undifferentiated portions of the original magma with which the volcanic reservoir was supplied on three occasions at least. From this original magma the other types may have been derived by some process of differentiation.

(1) It is hardly likely, at this stage of the progress of petrographical science, that any geologist would be found to support the idea of a separate magmatic origin for each type of lava represented in the series. Although in the island of Hawaii the two volcanoes, Kilauea and Mauna Loa, are quite independent one of the other in their periods of activity, the products of this activity are similar.

In the present case, however, it would be necessary to suppose that at least four volcanoes existed in such proximity that, in their various periods of activity, their lava-flows would have overlapped. As stated earlier, the field-evidence shows that the lavas all flowed down the same slope, and that the time-interval which separated different eruptions was in no case great. There is, in addition, so evident and close a relationship, from a chemical standpoint, between the various members of the sequence as to necessitate some amount of community of origin.

(2) The existence of two primary magmas and their combination in different proportions to form the multiplicity of igneous rock-

[1] Trans. N.Z. Inst. vol. xxxviii (1905) pp. 482–95; also 'Inclusions in some Volcanic Rocks' Geol. Mag. dec. 5, vol. iv (1907) p. 497.

types is the old theory of Bunsen, with its further extension by Durocher. This theory, so far as its general application is concerned, has at the present time a historical interest only. It is, however, worth while to consider the possibility of its application to a limited series of rocks such as the one now being considered. The two extreme types of rock found in this series would have to be taken as representing the composition of the two original primary magmas, and all the other types (phonolite, kaiwekite, trachydolerite, and basalts) would have to be regarded as formed from these two magmas mixed together in different proportions.

The two extreme types are the trachyte No. 1 and the basalt No. 6. It is, however, impossible to regard the phonolite No. 14, the most alkaline rock of the whole series, as formed from the mixture of these two primaries in any proportions whatsoever.

(3) The nature of the rock-sequence shows that the different members could not all owe their origin to the processes of differentiation that might take place in a single magma. Although temperature-differences and relative miscibility of various components of the original magma would almost certainly play their part in promoting such differentiation, yet it is not perhaps too much to say that, in the main, the separation of the magma into portions of different chemical composition would depend upon the action of the force of gravity. If this be admitted, it follows that the various lavas were emitted roughly in the order of their specific gravities. This, however, is far from being the case, for the phonolites are of much lower specific gravity than the basalts, yet they occur higher in the series than the basalts, and the very last lava of all is a phonolite.

What is true of the rocks as a whole is also true when applied to a consideration of the occurrence of different minerals in the rocks of the series. Thus barkevikite, a mineral with a high specific gravity, does not occur in any of the lower lavas, but only in those that are relatively high in the series, and in those lavas in which it does occur it is associated with anorthoclase, a mineral of relatively low specific gravity. While the occurrence of the rocks in the order of their specific gravity would, in the main at least, be due to the action of molecular differentiation, the occurrence of minerals in their order of specific gravity would be the result of fractional crystallization. Since neither the rocks nor the minerals occur in this series in an order which on the whole has any relation to the order of their specific gravities, it follows that the order of occurrence of both the minerals and the rocks goes far to show that the series of lavas has not originated from the differentiation that might have taken place within a single magmatic mass.

(4) The chemical relationship of the kaiwekite No. 13 and the trachydolerite No. 24 to the rocks above and below them shows at once how remarkably intermediate a chemical composition they possess. In regard to several of the constituents, notably lime,

magnesia, soda, potash, and, to a less extent, silica, it is seen at once that the proportions are almost the exact mean of those present in the associated rocks. This is clearly shown in the curves which represent the molecular proportions of the substances and in those which represent the molecular proportions of these substances as compared with silica (Pls. LIII & LIV). It can hardly be doubted that this indicates a genetic relationship. It must, however, be insisted that although the kaiwekite, for example, lies between a basalt and a phonolite, it must not be regarded as especially related to the basalt lying beneath it, but to the basalts that rest on the succeeding phonolite. The general similarity of the basalts of the series is, however, so great as not to invalidate the value of the comparison made. In point of fact, the probability of the genetic relationship is still further emphasized when in this case comparison is made with the basalts that rest upon the phonolite (No. 14). The lowest of these is distinctly less basic than the normal basalt of the series, and it can therefore be reasonably claimed as a differentiation-product of the kaiwekite-magma, connecting in a definite manner the phonolite and the basalt-differentiates. We are thus clearly led to the opinion that the kaiwekite represents the composition of the original magma in the volcanic reservoir, and that the phonolite and succeeding basalts are chemical differentiates from it.

The same relationship can be seen in connexion with trachydolerites Nos. 24 & 21: although in the former case any basalt that may have rested on the phonolite has been removed by denudation, and in the latter case there is no phonolite. This, however, is not surprising, for, as has been previously pointed out, all the lavas that issue from the crater of a volcano are not represented on a single slope of the mountain. It is indeed remarkable that a succession of lavas that can be regarded as a complete series, such as that above the kaiwekite, should be found on one slope. The occurrence of the trachyte at the base of the whole series is not explained by this suggestion. The rock on which it rests is not shown, but, as will afterwards be pointed out, there is, in the great magmatic reservoir of Tahiti, now exposed by the denudation of 6000 feet, at the least, of volcanic material, a mass of a syenite composed solely of felspar, and this has probably been derived from the differentiation of an essexite magma.

The foregoing statements support the belief that the lavas of this series have issued from a reservoir at an intermediate level, and that within this reservoir the conditions allowed of differentiation. On four separate occasions this reservoir is supposed to have been supplied from some deeper source with an essexitic magma in which a certain amount of crystallization had taken place. There is even some evidence that a certain amount of differentiation had already occurred in this deeper source, as the markedly porphyritic types of rock—trachyte No. 1, kaiwekite No. 13, trachydolerite No. 20, and trachydolerite No. 24, show a progressive decrease in silica and corresponding

increase in the basic constituents. There are, of course, other instances in which appeal has been made to the probability of fresh accession of magma to the reservoir. The best known is perhaps that of the Berkeley Hills in California, where five or six such recurrences are suggested. In this case, however, there is not so clear a succession of lava-flows, and the succession does not include alkaline rocks.[1]

The mineralogical and textural character of the rocks also supports this idea. The kaiwekite and trachydolerites contain phenocrysts of certain minerals that are not found in the other rocks, which it is here suggested are derivatives from the magma that solidified into the kaiwekite. Of these barkevikite, anorthoclase, and the violet augite are the most prominent. The olivine in these rocks also is far less fresh than it is in the basalts, and is often much resorbed. In fact, none of the principal minerals in the kaiwekite (and to a less extent in the trachydolerites) occur in the rocks which are supposed to be derived from the same material. At first sight, these considerations seemed to be an absolute barrier to the idea of the derivation of these lavas from a common source by a process of differentiation. Further consideration, however, somewhat lessened the difficulties. The olivine and perhaps the brown augite-phenocrysts in the basalts might be directly derived from those minerals that were already crystallized in the magma: for, when it came to rest, they would gradually sink to the bottom, because of their relatively high specific gravity, and this fact might well account for their absence in the phonolite and their presence in the basaltic derivative from that magma. The total absence of the barkevikite and partial absence of the anorthoclase in all the succeeding rocks must obviously involve considerations of a different nature.

Microscopic study shows that the barkevikite of the kaiwekite and trachydolerites has undergone much resorption, and that the anorthoclase has been greatly corroded. This at least suggests that, under the conditions of eruption of the magma, crystals of these two minerals were unstable. They are certainly crystals of intratelluric origin formed under conditions that obtain at great depth, but not proper to the composition and other conditions of this magma when it had reached the level of the supposed intermediate reservoir. It appears to be generally recognized at the present time that pyrogenetic hornblende will not crystallize unless the magma contains water or hydroxyl. Thus Prof. J. P. Iddings says

'according to Penfield hydroxyl enters into the composition of hornblende.[2] . . . The presence of hydrogen in the compound [pyrogenetic hornblende], though in smaller amount than in mica, indicates a similar origin for amphibole and mica compounds, namely a hydrolitic one.'[3]

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[1] A. C. Lawson & C. Palache, Univ. Calif. Bull. Dep. Geol. vol. ii, No. 12 (1902).

[2] 'Problems of Petrology' Proc. Am. Phil. Soc. vol. l (1911) p. 291.

[3] 'Igneous Rocks' New York, vol. i (1909) p. 139.

For a long time it has been widely known that water-vapour plays an important part in most volcanic action, and that it is a component substance of most igneous magmas. Exception has, however, to some extent been made in the case of the lavas of Hawaii, but it has lately been shown by Messrs. A. L. Day & E. S. Shepherd that water is a most important substance in that magma.[1]

At the present day we are justified in saying that water is an important constituent of all igneous magmas, except perhaps the ultrabasic material.

The kaiwekite magma would therefore contain water, and in virtue of the presence of this substance barkevikite might crystallize in it. Little appears to be known at present regarding the rate of resorption of such minerals, but there is no reason to suppose that a period of rest at the level of the intermediate reservoir would not allow of the complete resorption of all crystals formed under plutonic conditions. This would be almost certain to happen, if the distance of this reservoir from the surface, and other conditions, allowed of the escape of water-vapour.

After this complete refusion differentiation might take place. This would be of a molecular nature, for no crystals would be present in the magma. The low specific gravity of the phonolite compared with that of the basalt, suggests that the force of gravity would be the main agent in effecting this differentiation. To what extent gravity might have been aided by local differences of temperature and by relative want of miscibility of the femic and salic minerals, it is probably impossible to guess—at any rate, in this instance.

It thus appears that, although the mineralogical and textural characteristics of the kaiwekite and associated trachydolerites suggest at first sight that these rocks represent the final residue of the magma after cooling and crystallization had proceeded almost to their final limit, a closer consideration points to a conclusion which is wholly opposed to that idea. It supports the belief that these rocks in reality represent the original undifferentiated magma, and that the phonolites of fine texture are actually the products of molecular differentiation after the crystals that had originally crystallized had been completely resorbed into the magma.

The suggestion is thus made that the phonolites and basalts are the products of a differentiation of an essexitic magma. This is wholly opposed to the conclusion to which I came in 1906, when discussing the nature and relations of the igneous rocks throughout this district—for it was then stated that the trachydolerites (the phonolitic type of Rosenbusch was then alone referred to this group) and the basanite 'have resulted from the mixture of magmas before ejection.'[2] The strong light that has been shed on the whole question from a prolonged study of the North Head causes me to regard these intermediate types as resulting from the eruption

[1] Bull. Geol. Soc. Am. vol. xxiv (1913) pp. 573–606.
[2] Q. J. G. S. vol. lxii (1906) p. 421.

of the original undifferentiated magma; not from the complete intermingling of two magmas widely different one from the other in chemical composition.

The occurrence of the alkaline and basic rocks in the island of Tahiti is of special interest in this connexion. Here, as is well known, Prof. A. Lacroix has recorded the occurrence of phonolites and other alkaline rocks, as well as a great variety of basalts, some of which are of extremely basic composition. There is also in the interior of the island a mass of plutonic rocks which are mainly monzonites, essexites, and theralites.[1] A recent visit to that island, made for the purpose of studying these rocks, has enabled me to make a comparison between the rocks of the two districts.

On the outskirts of the plutonic area in the centre of the island, 6000 feet below the summit of the fantastic ruins of the great island volcano, occurs a pure white syenite composed almost solely of anorthoclase. At another place on its border a peridotite occurs, but over the greater part of the plutonic area there is a large outcrop of essexitic and theralitic rock. Viewed under the microscope, there is almost perfect identity between the barkevikite, violet augite, and olivine of these rocks and the same minerals found in the kaiwekites and trachydolerites at Dunedin. Here, again, the phonolites that issued from the crater which at one time reached more than 6000 feet above the surface of the plutonic rocks (as at present exposed) are dense compact rocks. The nature of the plutonic complex leaves no room for doubt that, in this instance at least, the phonolites resulted from the differentiation-processes within an essexitic magma. There is a close similarity between the rocks of Tahiti, Rarotonga, Moorea, Huaheine, and Raiatea, in all of which dense phonolites are associated with basalts often having the same extremely basic character as that presented by the basalts in Tahiti.[2] These facts suggest that they also have had a similar origin, and that here at least the usual origin of phonolitic rocks is from processes of molecular differentiation within a magma of essexitic composition.

Difficulties in obtaining access to any large body of geological literature have prevented me from making a comparative study of the theories that have been advanced to account for the origin of alkaline volcanic rocks. The only two that I can find—apart from general statements in text-books of the relation of phonolites, for instance, to nepheline-syenites — are those of Dr. Jensen and Dr. Daly. Unfortunately neither of these authors quotes literature on the subject. Dr. H. I. Jensen states, among other conclusions in his summary[3]:—

(1) All alkaline rocks are practically confined to the flanks of old plateaux (continental areas) which have escaped heavy sedimentation in late Palæozoic

[1] Bull. Soc. Géol. France, ser. 4, vol. x (1910) pp. 91–124.

[2] For a general statement, see P. Marshall, 'Oceania' in 'Handbuch der Regionalen Geologie' vol. vii, pt. 2, Heft 9, p. 12 (Heidelberg, 1911).

[3] 'The Distribution, Origin, & Relationships of Alkaline Rocks' Proc. Linn. Soc. N.S.W. vol. xxxiii (1908) p. 584.

and Mesozoic times. . . . (4) Very old rocks, often the Archæan complex, occur in or very near every alkaline province. . . . (7) For reasons given, the theory is advanced that alkaline rocks are derived from, in the first place, Archæan saline beds which, by chemical attacks on the adjacent sediments, have given rise to an alkaline magma in the process of metamorphosis. This magma has been squeezed laterally into the continental areas and has undergone differentiation, or it has mixed with other magmas, chiefly basic, and has then been differentiated.

It appears heroic to attempt to apply No. 1 to the case of Tahiti, for the soundings round the island are all of great depth, and no structure that can possibly be regarded as the old plateau exists nearer than Australia. In Dunedin it is true that the alkaline volcanic rocks occur on the border of a schist-area. I have, however, elsewhere given reasons for the belief that these schists are of Mesozoic age.[1] As to 4, very old rocks are not known anywhere near the alkaline rocks of the Pacific Islands. In New Zealand the supposed Archæan gneisses are 150 miles distant. With regard to 7, the statement of the origin of alkaline rocks is partly based on 1 and 4, and must stand or fall with them.

Dr. R. A. Daly tentatively ascribes the presence of trachytes and trachydolerites among the basalts of Hawaii to changes in the normal basalt arising from its solution of small quantities of sedimentary limestone cut by the respective lava-conduits. Generally, he has stated more recently that

'The segregation of alkalies and the observed desilication of subalkaline magmas are largely explained by the assimilation of the natural carbonates. It is conceived that the whole of the carbonates may take part in the appropriate chemical reactions, or that sometimes the subalkaline magma is affected only by the carbon dioxide that is given off by magmatic heat from invaded limestone into the volcanic vent or other magmatic chamber.'[2]

In Tahiti no included fragments of limestone have yet been found in the volcanic rocks. In the magmatic chamber syenites, essexites, monzonites, theralites, peridotites are all found, and it is probable that all these divergent types result from the differentiation of one original basic magma with a high content of alkalies. So far as the required limestone is concerned, appeal would have to be made to the *Globigerina* ooze that certainly covers the sea-floor in the neighbourhood of these islands.

Near Dunedin the only limestone known is a highly siliceous rock. No fragments of this have been found in the volcanic rocks, and there is a notable absence of types of siliceous rocks in the volcanic series. In addition, the relations of the rocks of this series, as described above, seem to demonstrate that the phonolites and basalts have both been derived from an essexitic magma by molecular differentiation.

[1] 'New Zealand & Adjacent Islands' in the 'Handbuch der Regionalen Geologie' vol. vii, pt. 1, Heft 5, p. 18 (Heidelberg, 1911).

[2] 'Origin of the Alkaline Rocks' Bull. Geol. Soc. Am. vol. xxi (1910) p. 115.

While the statements made and arguments advanced in this paper give a satisfactory and reasonable explanation of the occurrence of phonolites in genetic association with basalts in the Dunedin district, as also in Tahiti and probably in the other islands of that part of the Pacific basin, it is not supposed that this explanation necessarily accounts for the occurrence of phonolites in other volcanic districts. There are not sufficient data derived from a study of this district to justify a discussion of the origin of the essexitic magma itself.

VI. Summary and Conclusions.

(1) The series of volcanic lavas at the North Head, Dunedin, all flowed down the same slope, and probably all issued from the same volcanic orifice.

(2) The large amount of scoria between the lava-flows shows that the centre of eruption was not far distant from the locality of the North Head.

(3) The fact that there was no erosion of any lava-flow before the outflow of the next indicates that no interval of any great length separated the eruption of the various lavas.

(4) The lavas may be classified as trachyte, phonolite, kaiwekite, basalt, and trachydolerite.

(5) The trachydolerites and kaiwekite have an intermediate composition between the phonolites and the basalts.

(6) The trachydolerites and kaiwekite contain large crystals of barkevikite and of anorthoclase or of nepheline, and are much the most porphyritic rocks of the series.

(7) Although these rocks are the most porphyritic of the succession, their intermediate chemical character marks them as formed from the magma before it was differentiated.

(8) This consideration necessitates a threefold eruption from a deep-seated source to an intermediate level.

(9) After a partial eruption of the magma at this intermediate level complete resorption of the barkevikite and other minerals would take place.

(10) The eruption of the dense non-porphyritic phonolite would take place from the upper part of this residue, which would have become separated into portions chemically different by the process of molecular differentiation acting under the force of gravity.

(11) The basalts represent the heavier residue of the differentiated residue at the intermediate level.

(12) The barkevikite, violet augite, anorthoclase, and basic felspar, which occur as phenocrysts in the intermediate lava, as well as the chemical composition of these lavas, prove that the original magma had the composition of essexite.

(13) The course of differentiation which is indicated in the series of lavas exposed at the North Head is apparently the

same as in the island of Tahiti, where there is a similar assemblage of alkaline and basic lavas.

(14) In Tahiti erosion has now exposed the reservoir, and the dominant type of rock seen in it is essexite, although the lavas of the island are remarkably free from the hornblende which is the most conspicuous mineral of the essexite.

(15) It is suggested that the frequent occurrence of alkaline and basic rocks at Moorea, Huaheine, Raiatea, and Rarotonga is due to differentiation from an essexitic magma.

EXPLANATION OF PLATES LIII & LIV.

Plate LIII.

Diagrams showing the chemical composition of the lavas and the molecular proportions of the oxides in the series of rocks.

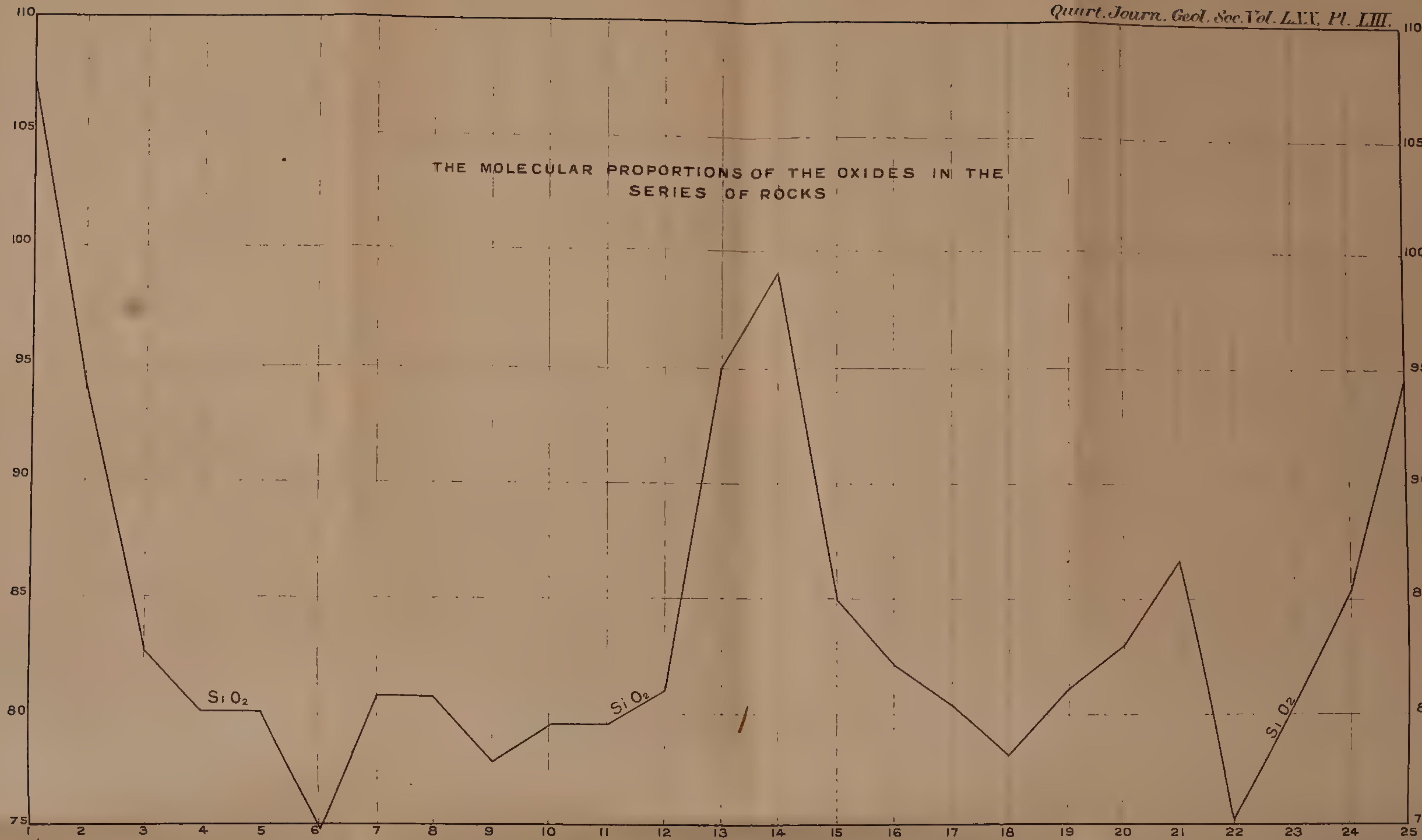
Plate LIV.

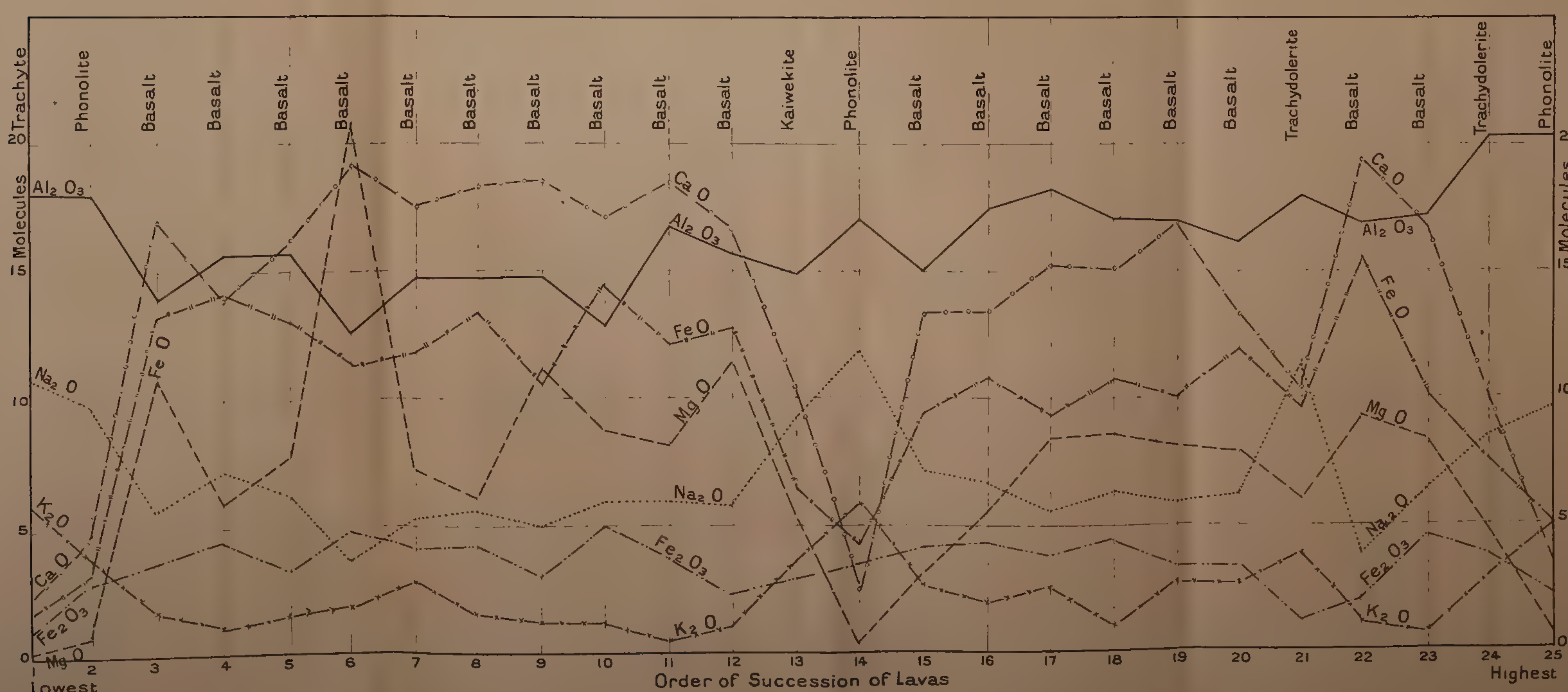
Diagram showing the specific gravities; and variation-diagram of the molecular proportions of the metallic oxides compared with silica, which in each case equals 100.

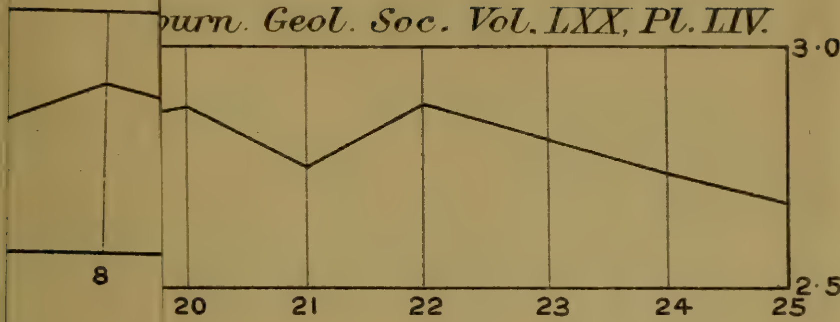
Discussion.

Dr. J. W. Evans expressed his pleasure at this valuable addition to the evidence bearing on the subject of the differentiation of igneous magmas, although he agreed with Prof. Brögger that the variations among volcanic rocks did not afford such definite information as the order of intrusion among intrusive rocks, of different composition but proceeding from a common source. He remarked on the predominance of basaltic lavas in the succession described, and expressed his opinion that the magma from which the intrusions proceeded must have had the composition of a basalt somewhat rich in soda. In a communication to the Twelfth International Geological Congress at Toronto, he had expressed the opinion that in the presence of the elements of water in considerable amount, a clear differentiation was possible into a magma corresponding to a granite in composition (except that it contained a much larger amount of water), and a basic magma with little water. Where water was deficient, the separation was less complete, and the basic magma was richer in soda. At the same time, there was evidence that an alkaline magma tended to separate into layers of different composition when cooled to a temperature but little above that at which crystallization commenced. In the present instance, this appeared to have resulted in the separation of a comparatively small amount of more acid rocks from the main magma.

He deprecated the use of very special terms like kaiwekite, side by side with general terms such as basalt. It was regrettable that something like the distinction made in biology between family, generic, and specific names could not be introduced into petrology.


THE MOLECULAR PROPORTIONS OF THE OXIDES IN THE SERIES OF ROCKS
Si O2


Trachyte
Phonolite
Basalt
Kaiwekite
Trachydolerite
Molecules
Al2 O3
Ca O
Fe O
Mg O
Na2 O
Fe2 O3
K2 O
Lowest
Highest
Order of Succession of Lavas



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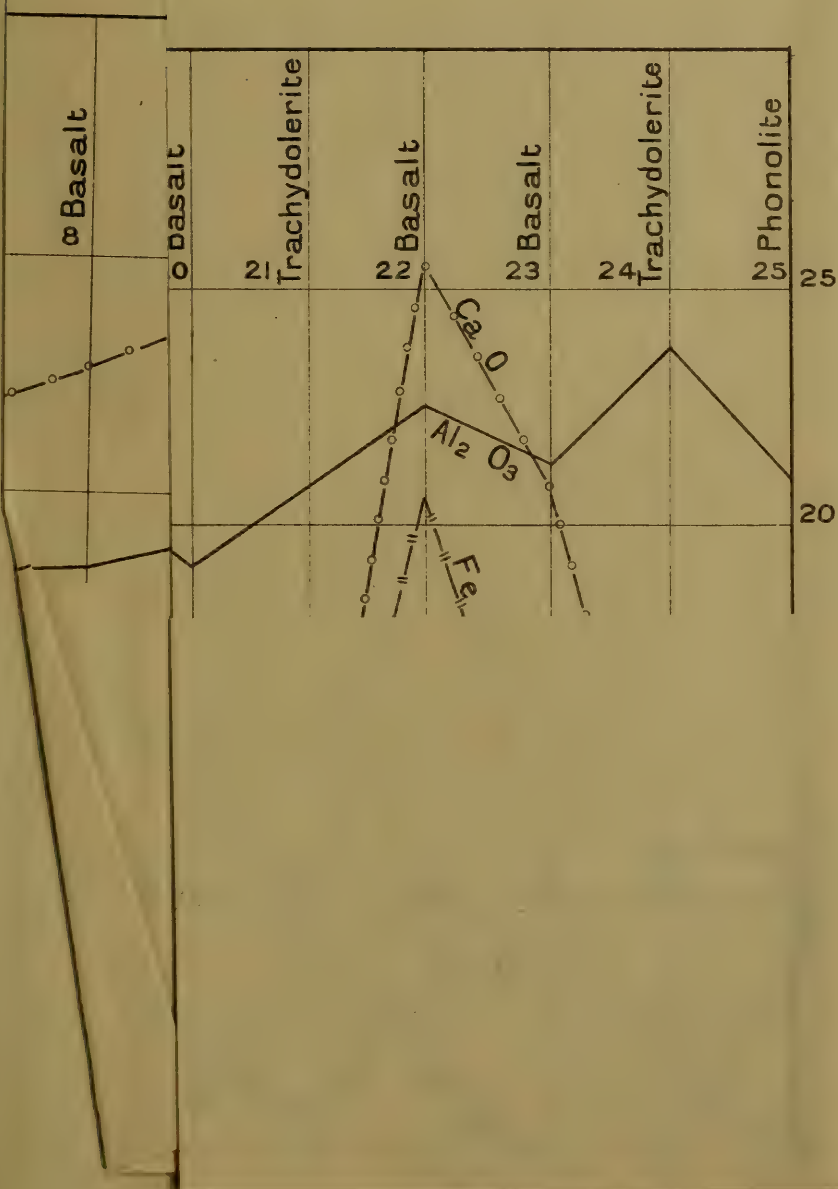
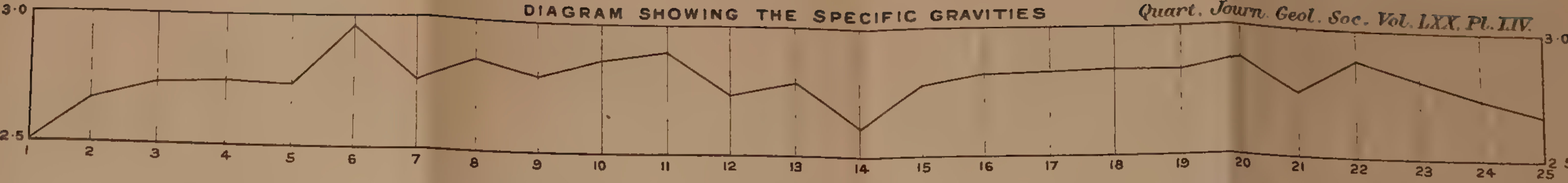
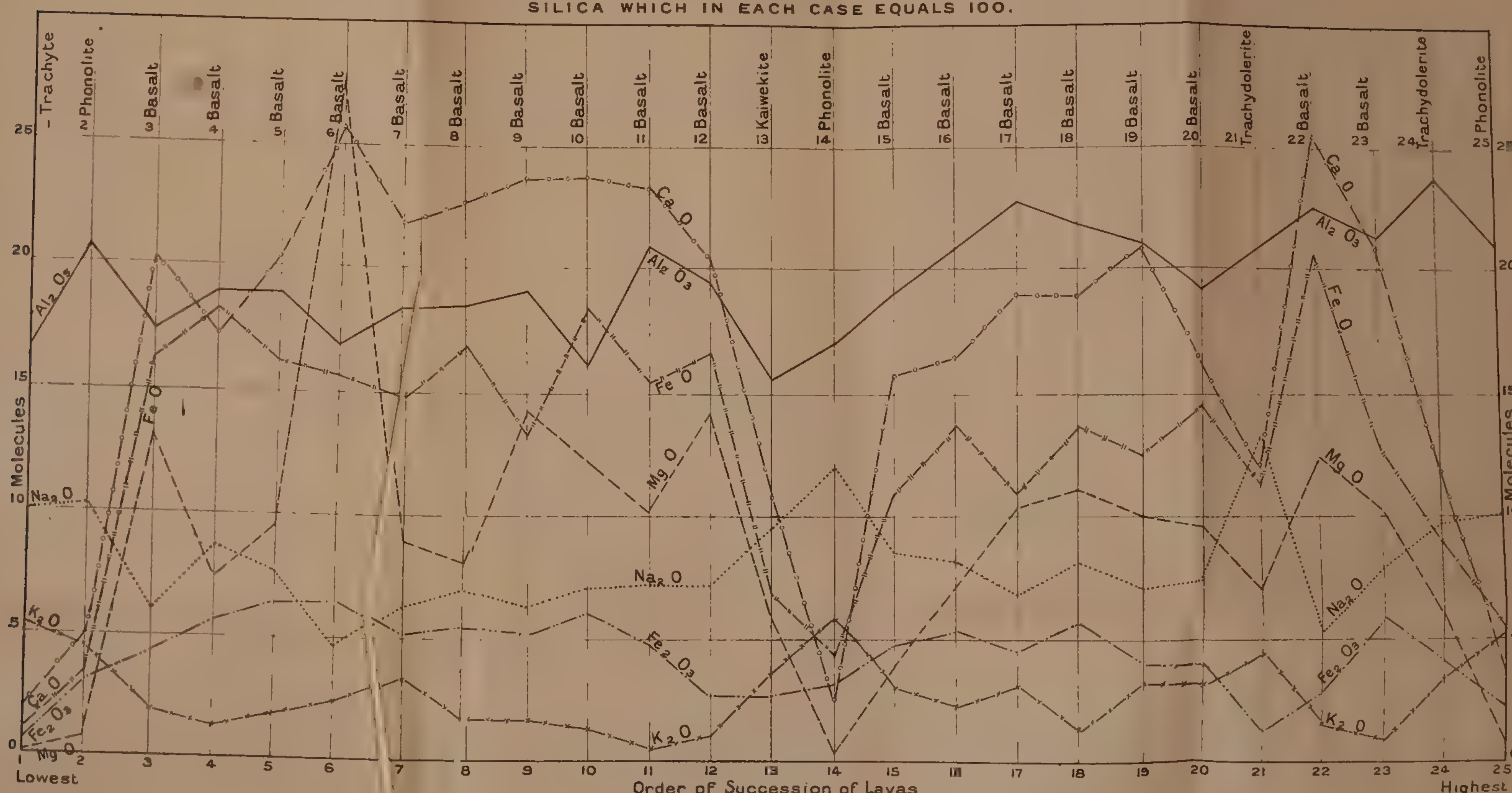


DIAGRAM SHOWING THE SPECIFIC GRAVITIES



VARIATION-DIAGRAM OF THE MOLECULAR PROPORTIONS OF THE METALLIC OXIDES COMPARED WITH SILICA WHICH IN EACH CASE EQUALS 100.



For the purpose of the present paper it would have been better to describe the kaiwekite simply as a soda-trachyte.

Mr. J. F. N. GREEN observed that there was some danger in generalizing from a single section of lava-flows of unknown extent. He enquired whether there was proof that the bands of scoria referred to were really intercalated beds, and not merely surface flow-breccias.

Mr. F. P. MENNELL said that on points like the succession of eruptions too much information could hardly be amassed. It was doubtful, however, whether it threw much light on the constitution of the magmas that had existed down below, for lavas seemed rather to be in the nature of a scum which was strained off and forced to the surface. Quite apart from hypothetical considerations, it was interesting to note that the section described by the Author, like so many others from the so-called 'provinces' of alkaline rocks, showed numerous non-alkaline flows. It was not sufficiently recognized that, in even the most richly alkaline regions, rocks containing felspathoids were the exception rather than the rule; but petrographers were generally too anxious to devote their attention to the rare and curious to take much account of the more normal types. He was inclined to agree with what Dr. Evans had said regarding nomenclature: the multiplication of names was to be deprecated, and it did not seem at all desirable to have those that denoted rare varieties put on a level with such comprehensive terms as basalt.

Dr. J. V. ELSDEN said that the Author had evidently made good use of an excellent opportunity of studying an extended sequence of eruptive phenomena; but these lavas represented only one phase of the vulcanicity, and it seemed somewhat remarkable that no indications of intrusive dykes appeared to exist in this area. With regard to the process of differentiation assumed by the Author, this necessarily involved the origination of these several flows in the same magmatic basin. Although such an origin seemed to be highly probable, he would like to examine more closely the evidence upon which this fundamental conclusion was based, as well as the chemical differences of the various rock-types described by the Author, and considered by him to be derivatives of a parent essexite-magma. For this purpose it was necessary to know, not only how far certain molecules were missing (in comparing, for example, the felspar with the felspathoid types), but also how far these had merely entered into different molecular arrangements. The Author had brought forward a large mass of valuable information, and the Fellows were to be congratulated upon having this important paper submitted for their consideration.

Dr. A. H. COX remarked on the interest of the paper, which dealt with a district offering yet another example of the well-known tendency for volcanic phases of igneous activity to begin with the emission of lavas mainly basaltic in type. He considered that the coining of a new name for a particular rock often made

for greater clearness than would the attempt to describe it under one of the older terms, which otherwise tend to lose their definite meaning. With regard to the suggested connexion between the lavas of intermediate chemical composition and an original essexite-magma, he enquired as to the sense in which the term essexite was used by the Author.

Dr. H. Lapworth, in reply, read portions of the paper, and answered, as far as he was able to do so in the Author's absence, the many questions raised.

GENERAL INDEX

TO

THE QUARTERLY JOURNAL

AND

PROCEEDINGS OF THE GEOLOGICAL SOCIETY.

END OF VOL. LXX.

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PROCEEDINGS

OF THE

GEOLOGICAL SOCIETY OF LONDON.

SESSION 1913-14.

November 5th, 1913.

Dr. Aubrey Strahan, F.R.S., President, in the Chair.

The List of Donations to the Library was read.

The following communication was read:—

'Geological Sections through the Andes of Peru and Bolivia.' By James Archibald Douglas, M.A., B.Sc,, F.G.S.

Rock-specimens and lantern-slides were exhibited by the Author, in illustration of the above paper.

November 19th, 1913.

Dr. Aubrey Strahan, F.R.S., President, in the Chair.

Francis Matthew Ball, Royal Colonial Institute, Northumberland Avenue, W.C.; William Noel Benson, B.Sc., Emmanuel College, Cambridge; Horas Tristram Kennedy, B.A., 14 Hume Street, Dublin; Stanley Eli John Lock, B.Sc., 20 Bradford Road, Trowbridge (Wiltshire); William Wylie Macalister, Ceres, St. Mildred's Road, Lee, S.E.; Charles Henry McCale, Sitarampur P.O., E.I.R., Bengal (India); and Vivian Mortlock Studd, 23 Montpelier Square, S.W., and Elmhurst, Camborne (Cornwall), were elected Fellows of the Society.

The List of Donations to the Library was read.

No papers were read, but in response to the invitation issued on November 5th, eighteen or more exhibits were made of implements and reputed implements of Palæolithic and earlier age, and of flints showing various types of fracture.

The PRESIDENT (Dr. A. STRAHAN), in opening the proceedings, said that the subject which had come before the Society for consideration was partly of anthropological interest, but fell also within the limits of geology. For the exhibits included specimens of flints from strata ranging in age so far back as the base of the Crag; and the determination of the age of the strata was clearly a matter for geological investigation.

The specimens exhibited included some for which evidence of human workmanship was claimed with much confidence, but without having obtained universal acceptance. There were also shown series of flints illustrating the manifold forms of fracture which are attributable to natural causes. A comparison of these with the reputedly artificial forms could not fail to be instructive.

A large number of flints, for which a human origin was claimed, had been found lying on the surface or embedded in the soil. These were chiefly of anthropological interest.

He considered that there were four lines of enquiry of primary importance:—

(1) Were the specimens obtained *in situ* in a geological formation?
(2) What was the geological age of the formation?
(3) Did the flints show indubitable proof of the handiwork of Man?
(4) Could such a sequence of types of implements be established in this country as to enable geologists to use implements as zone-fossils in the deposits of the Human Period?

He then called upon each exhibitor to explain briefly the nature and object of his exhibit.

Mr. J. R. MOIR exhibited specimens which included (1) implements from the base of the Suffolk Red Crag, comprising the well-known rostro-carinate type, borers, pointed forms, flakes and scrapers: also some Cetacean bones which presented the appearance of having been fashioned by man; (2) flints flaked by the exhibitor, showing the various stages in the manufacture of a rostro-carinate implement; (3) four groups of implements from the Middle Glacial gravel underlying Boulder Clay; (4) a series of implements from the Boulder Clay; and (5) a series of implements of the Strépy type of M. Rutot, from a Glacial gravel apparently later in age than the Boulder Clay.

Mr. F. N. HAWARD exhibited a series of bulbs of percussion and facetted flints, many with edges chipped on one or more sides, from Glacial gravels and the Cannon-Shot Gravels of Norfolk. He pointed out that the large rounded flints from the Cannon-Shot Gravels were a mass of cones of percussion, some exhibited being

$1\frac{1}{2}$ inches in diameter at the base, and of character similar to those produced artificially. From a Glacial gravel at Lenwade specimens were shown of tabular flints with chipped edges, and others which simulated closely the 'hollow scraper' and 'one-edge' work usually attributed to the hand of Man. From gravel at Tuddenham, full of split flints fresh from the Chalk, the edges of the flints exhibited were chipped almost entirely from one side: this chipping he attributed with confidence to natural agencies. For some years he had been working at certain types of chipped flints which some would consider artefacts, but concerning which he had grave doubts; and he had collected a large series from a pit at Eaton, near Norwich. This pit from its basement-bed, which is 1 foot thick, yielded a remarkable series of flints with chipped secondary edges of various shapes. The basement-bed consisted of three zones: the lowermost zone was made up of Chalk in process of disintegration. The middle zone consisted entirely of much-fractured Chalk-flints, many of which come away as a mass of splinters and contain bulbous flakes: the splitting of these flints was due to crushing *in situ* under great pressure, but the flakes show little or no secondary chipping. The top zone yielded all the chipped specimens that he exhibited, and he pointed out that they all came from one face of the pit; that they were collected in a horizontal distance of 12 feet; and that they were picked out by hand. The specimens are generally scratched all over, and many show remarkable selective work on one edge.

A like series was also exhibited from a similar basement-bed at Harford Bridges. They also occur at East Runton, and in many other places where the basement-bed is exposed. The so-called 'implements' generally occur where the basement-bed is most crowded with flints.

In the speaker's opinion, these chipped flints were simply the result of crushing by natural forces which acted during the cutting away of the Chalk, either by ice or snow before the gravels were deposited, or by lateral movement in the gravels under great vertical pressure. Whenever a moving stone impinged on the sharp edge of a stationary flint, chips would be flaked off the flint along the lines of least resistance; but when the sharp edge of the flint is turned away from the impinging force no chipping will ensue. As regards the direct proof that these chipped flints were Nature's work, it was next to impossible to reproduce the conditions under which the natural chipping took place, and to make observations in a gravel buried under hundreds of tons of soil, ice, and snow. The speaker had, however, been able to exhibit naturally-chipped flints which owed their character to the foundering of a mass of gravel in a pipe, the gravel breaking through a layer of flints in the Chalk.

Mr. S. H. Warren, in exhibiting the results of certain experiments upon flint, said that he wished to make it clear that these experiments were not conducted from the point of view of proving what Nature could do by the attempted simulation of

natural causes, but from the point of view of investigating the properties of flint. What he was endeavouring to elucidate by experiment was the manner in which flint chipped when subjected to forces of measured strength applied in different directions. Many methods were being used, one of which was that of movement under pressure of a sled, which could be loaded at will with different weights. This process resulted in the reproduction of the Kentish form of 'Eolith,' a load of 250 lbs. being sufficient for the production of most of even the larger forms. It was, however, insufficient for the reproduction of the big chipping often present upon the sub-Crag flints.

In considering subsoil pressures, in a soil of medium weight (a clay-with-flints) a stone having a superficial area equal to a rectangle of 8 by $6\frac{1}{4}$ inches was under a pressure of 250 lbs. at slightly less than 6 feet below the surface; at a depth of 50 feet the same stone would be under about 9 times that pressure, while beneath 500 feet of ice it would be under 40 times that pressure. It was important to remember that striated surfaces were associated with both the Kentish 'Eoliths' and the sub-Crag flints, and these pointed to the conclusion that strong movements under pressure had actually operated upon the flints in question.

Although the speaker did not wish to postulate too close an analogy between experimental and natural conditions, yet, if, broadly speaking, the chipping properties of flint discovered by experimental investigation could be relied upon as also applying under natural conditions, then such chipping as was seen on the flints in dispute might theoretically be expected to occur.

A small series of chipped flints obtained from the base of the Tertiary beds at Harefield was also exhibited. In this section the bulbous chips could be found in the facets of the parent blocks, from which they had been forced away by the operation of subsoil pressure.

Mr. A. S. KENNARD exhibited, on behalf of Mr. B. HARRISON, a series of Eoliths from the Chalk Plateau of West Kent. This type of worked flint was first described by the late Sir Joseph Prestwich, and had formed the subject of a considerable literature. It is obvious that the Palæoliths cannot be the earliest efforts of man, and, although some of the stratigraphical evidence of the Plateau is conflicting, yet, on the whole, it would appear that the 'Eoliths' are older than the Palæolithic gravels. This is clearly seen at Swanscombe, where the 'Eoliths' are certainly derivatives. In South Africa a similar sequence can be shown, and this is of the utmost importance. It was quite impossible to say definitely where the work of Nature ended, and that of Man began. It was purely a personal matter, but the speaker was confident that many of these rudely-chipped flints were human artefacts. As a group, they differed from the sub-Crag flints and many other so-called 'Eoliths.'

Colonel A. W. Jamieson exhibited a series of specimens that he had collected in the south-east of Hampshire, and he wished to draw attention to this district, for he thought that it deserved more consideration than it had yet received. The area is bounded on the north and west by the Meon, on the east by the Sussex border, and on the south is the Undercliff of the Isle of Wight. This country is strewn with worked flints of all ages, especially so from the Chalk-summit to the sea.

Worked flints were furnished by a series of gravels on the marine plain, summarized on the geological map as Plateau Gravel. The sections are good, and constantly varying on account of the rapid destruction of the coast.

The bottom layer of these gravels, which rests on denuded Bracklesham Beds, consists of Arctic Drift full of igneous erratics and crowded with flints of café-au-lait and ochre colour, together with subangular masses cut about in a manner similar to those exhibited by Prof. Sollas. So-called 'Eolithic' forms are abundant. Upwards early Palæolithic layers follow, with the conventional Drift-types, several of which were shown. On the top is the brick-earth or lœss, crowded with worked flints which have the appearance of being Aurignacian. They include steep-sided side-scrapers and segmental tools. In this deposit the speaker had discovered a human skeleton, *minus* the skull, the bones of which were now undergoing examination by Prof. A. Keith. Above the marine plain a point of interest is the conspicuous hill of Portsdown, which has yielded a vast number of flints, worked on one side, shorn off flat on the other, and bearing conspicuous cones and bulbs of percussion.

The high Chalk of the interior is in places patched with Clay-with-Flints that has withstood destruction, and is rich in fabricated flints, which, in the speaker's opinion, are chiefly Mousterian.

Implements were also shown from Catherington, Hixton, Windmill Hill, and Blendworth, the last-named locality being rich in segmental tools and half-finished work showing huge cones of percussion. The speaker urged the view that the Clay-with-Flints was a formation coæval with the history of Man.

Prof. W. J. Sollas exhibited a series of specimens to illustrate the production of 'rostro-carinate' forms of flint by natural agencies. One from the top of the Chalk at Swanscombe showed jointing *in situ*, and some from the beach under the Chalk cliffs of Alum Bay showed the effects of wave-driven pebbles; but the great majority were obtained by Mr. E. Heron-Allen from the beach at Selsey Bill, and it was to these that attention was especially directed. If they were all of human workmanship—Sir E. Ray Lankester's contention[1]—, there would be no difficulty in accounting

[1] [This is not Sir E. Ray Lankester's view: I regret that I have erroneously attributed it to him.—*W. J. S., December 12th, 1913.*]

for the characters which they possess in common, notably their abundant and bold flaking; but then the fact that some examples were bounded on one side by planes of Pleistocene age, and on the other by planes of recent origin, would remain unexplained. If, on the other hand, only certain specimens were selected as artefacts—Mr. J. R. Moir's interpretation—, then it became difficult to explain the flaking which they all possess in common; and the fact will still remain that 'rostro-carinate' forms may be produced by flaking of widely separate ages. Some of the flints showed recent chipping under circumstances which suggest that this had been produced by the blows of pebbles driven inland from the sea: that is, in one direction. Attention was also called to 'rostro-carinate' forms projecting from the side of a big boulder of flint.

The Rev. H. H. Winwood exhibited specimens of quartzite and flint-implements from the Broom, Farnham, and Knowle gravel-beds. His object was to show the gradation, from the well-worked implements of undoubted human origin, to the fractured specimens from the Brinkworth plateau-gravels 400 feet above O.D., the so-called 'Eoliths,' the origin of which is so much disputed. A porcellanous, or more probably altered-chert, implement from Somaliland and a flint-specimen from the cave-shelter at Le Moustier, showed how universally this type prevailed. Especial attention was called to a broken flint found by himself in the Knowle gravel-pit at Savernake, which had a remarkable glaze over the surface, not only on the fractured but also on the old surface, the cause of which yet awaited explanation.

Mr. H. N. Ridley exhibited a series of stone-implements from the eastern coast of the Malay Peninsula, found in river-gravel and in one case on a bed of alluvial tin-ore. Nothing further is known of the race which made these tools, and it is certain that it has long been extinct. He showed, in addition, some modern Papuan weapons of stone, in order to illustrate the methods of fastening the stones to the handles, and some tanged sandstone adzes with shell-ornaments and spindle-whorls from the lake-dwellings of Kampong Thom in Cambodia, also of unknown date.

Mr. O. A. Shrubsole exhibited a few specimens from the Reading district, in order to show difference of age and variety of use. The Eoliths were from the gravel of the Easthampstead plateau (300 to 400 feet O.D.). The Palæoliths included hollowed scrapers (highly developed from the Eolithic type), gimlets or drills, knives (sometimes with a tang for insertion in a handle), saws, choppers, pickaxes, and polishers: one of the last-named still bears a finger-print of ancient Man. Heavy two-handed choppers also occurred, identical in form with a specimen shown from the base of the Red Crag. Two at least of the Crag specimens were good Palæolithic types. He showed, in addition, three specimens of bone (radius and rib of *Bos*) which had been cut very neatly by a flint

instrument. Two flint-implements were also exhibited which, by the difference of patina, indicated that they had been reworked at a much later date.

Mr. W. Dale exhibited a series of naturally-formed or naturally-fractured flints; these included an assortment of flakes caused by the bursting or expansion of the flint. One of these, on the base of an Echinoid, remains *in situ*, and can be taken out and replaced in the cavity. Some specimens illustrated the 'starch-fracture' arising from the partly crystalline nature of the flint, and producing irregular prisms. From implementiferous gravels he exhibited a quantity of the fossil organisms known as *Coscinopora*. In the Chalk these are imperfectly pierced, but in the gravel the holes become enlarged, and Sir Charles Lyell and Mr. Worthington Smith thought that they might have been used as ornaments. The specimens shown were obtained from a gravel-digger, who was in the habit of placing them on strings. Flints which simulate Palæolithic implements in their form were also shown, and a collection of natural shapes somewhat resembling animal forms—one of them strikingly like a human head. The speaker would not have thought it worth while to show these last, but for the fact that the vagaries of the late Auberon Herbert had found another exponent, and the Journal of the British Archæological Association had this year published drawings of a number of these objects and advanced them to the dignity of artefacts.

Mr. N. F. Robarts wished to draw particular attention to some of the Eoliths which he exhibited, found upon the plateau of the North Downs in Surrey, at 800 feet above O.D., near the crest of the escarpment. Of these some were rolled, and it was therefore evident that they must have been derived from the Chalk dome which formerly existed over the Weald.

Mr. G. W. Lamplugh showed a fragment of glaciated claystone of rectangular shape from the Boulder Clay of a Flintshire colliery-shaft, as an example of the artificial aspect occasionally brought about by natural fracture. The shape of this example was remarkably close to that of a manufactured whetstone. The speaker observed that, where the cause of fracture was uncertain, it became of prime consequence to know the proportion that selected specimens bore to the total number examined: since, if the supply of naturally-fractured stones be unlimited, exceptional types, such as the specimen that he exhibited, must occasionally be found.

Mr. W. H. Cook exhibited fifty examples of Eoliths and thirty Palæoliths collected from the northern flank of the Weald. As a result of his investigations, the speaker questioned the pre-Palæolithic age of the Eoliths of this area: for, during the last six years, he had found considerable numbers of Palæoliths lying in conjunction with Eoliths on the surface, at levels ranging from

450 to 765 feet above O.D. The implements of both classes are in a precisely similar mineral condition, and the amount of abrasion is likewise common to both. A typical Kentish Eolith is a deeply-patinated nodule of flint with one or more of its edges chipped, such chipped edges being in general of a lighter ochreous patination than the other parts of the nodule. It was noteworthy that some of the deeply-patinated Palæoliths had a subsequent or re-chipped edge showing exactly similar characteristics in regard to patina and angle of chipping as the Eoliths with which they were associated. It had been said that Palæoliths did not occur beneath the humus, but the speaker had had excavations made at levels of 450 and 520 feet above O.D. At the lower level he had found numerous Eoliths and a rolled Palæolithic flake at a depth of 4 feet 6 inches; and at a further depth of 2 feet he found unrolled unochreous Eoliths. At the higher level he had detected a much-rolled Palæolithic implement, in conjunction with numerous Eoliths. He considered, therefore, that the contemporaneity of Eoliths and Palæoliths was beyond doubt.

Mere crudity of the fabrication of an implement could not be regarded as an indication of pre-Palæolithic antiquity: for, if that were allowed, many rudely-fashioned implements, found associated in the drifts of our river-valleys with the higher forms and on the surface with polished tools, would have to be regarded as of greater antiquity than the finished examples, whereas there was good evidence to the contrary. This claim to a pre-Palæolithic antiquity for implements of crude workmanship could not be upheld, when with them were found Palæolithic implements of Chellean and Acheulian types, in precisely the same mineral condition and showing a like amount of abrasion.

Mr. Reginald A. Smith referred to the type-series of flints from the excavations carried out in 1912 on behalf of the Geological Survey and the British Museum. The official account was about to be published by the Society of Antiquaries ('Archæologia,' vol. lxiv), and dealt with the 100-foot terrace-gravels at Milton Street, Swanscombe, long known as a most prolific site. The 35-foot section of Pleistocene deposits contained three bands of gravel, separated by two bands of loam. The lowest gravel, resting on Thanet Sand, contained a large number of struck flakes, unrolled and without secondary chipping—but no implements in the ordinary sense of the term, though some chipped cylindrical nodules might be regarded as of Strépy type. The Chellean types occur abundantly in the middle gravel, especially in its lower section, the industry higher in the same bed showing an approach to Acheulian forms; but, though the latter had been found from time to time in the pit and in the vicinity, no results were obtained during the excavations. Subsequently Mr. Dewey had acquired a series of unrolled Acheulian implements, mostly twisted ovates, from a bed corresponding to the upper gravel, in an adjoining pit. Hence the whole series, generally known as the Drift, seemed to be represented in the 100-foot

terrace-gravels, as was also the case in the Somme Valley. This did not preclude the possibility of Drift-forms occurring in gravels at higher or lower horizons; and recent discoveries on the North Downs and other sites in the South-East of England suggested that some of the beds mapped as Plateau-Gravel were laid down or re-arranged in the period named after St. Acheul.

The PRESIDENT (Dr. A. STRAHAN) then invited discussion on the above-mentioned exhibits.

DISCUSSION.

Mr. WALTER JOHNSON asked whether it was a fact that, at depths below 6 to 8 feet on the Kentish plateau, Eoliths only were found. The objection against the selection of types should not be pressed too far: for while, in extreme cases, selection resulted in an assemblage of absurd 'figure flints,' yet it was actually the plan followed in identifying Palæoliths—the searcher looked for implements that corresponded to known types, which from previous experience he had come to regard as artefacts. Since Mr. Haward, in a recent paper, admitted that a few of the Eoliths might have been 'humanly chipped,' and since Prof. Sollas at the British Association a few years ago seemed willing to accept 1 or 2 per cent. as genuine, would it not be well for those gentlemen to indicate exactly which specimens they considered to show human workmanship, so as to help in the attainment of an approximate standard of agreement?

Prof. W. BOYD DAWKINS said that this admirable exhibition brought clearly before them the fact, recognized by the French archæologists, that flints can be so broken by natural causes as to simulate the forms that have been made by Man—flakes and variously-chipped blocks. Consequently, in dealing with the antiquity of Man, it is necessary that the specimens on which it is based should be clearly proved to be artefacts. This, in his opinion, had not been proved in the case of the Ipswich finds, on which Mr. J. R. Moir and Sir E. Ray Lankester based their conclusion that Man was living in Suffolk in the Pliocene Age. The supposed artefacts are probably caused by the pressure of the dead weight of gravel on the move down the slopes, or by other pressure, such as that of ice. On the question of the age of the deposits in which they are found, the archæologists must refer to Geology as a final court of appeal. They have no right to invent glacial periods, or to correlate strata in Britain with the glaciers in the Alps.

The 'Eoliths' are clearly proved to be due to natural causes, not only by their range throughout the gravels from the Eocene downwards, but by careful observations made in France and in Britain.

In the Palæolithic enquiry too much stress has been laid on the various levels of the gravel-terraces, and Man has been treated as if he were aquatic, and unable to wander down hill and up dale.

If archæology is ever to become a science, it will be by dividing the objects discovered into three groups:—(*a*) those unmistakably proved to be of human origin, and of clearly-defined geological date; (*b*) those which are non-proven, and go to 'the suspense account' suggested by the late Lord Avebury; and (*c*) those which are not worth further consideration, and may be thrown on the refuse-heap. The first group alone can be used for scientific purposes, and in illustration of the last we may take the flint-nodules simulating quadrupeds, birds, and fishes, considered by Auberon Herbert and others as the work of Palæolithic Man.

Mr. J. R. Moir emphasized the difference in form and flaking of the flints from the sub-Red Crag detritus-bed, the Middle Glacial gravel, Chalky Boulder Clay, and Glacial gravel. He added that, if Man had not been the producing agent responsible for these specimens, then it must be supposed that Nature had broken flints in distinct and different manners at different periods in the past—a view which he was quite unable to entertain.

The speaker explained how it was possible to produce a true rostro-carinate implement by the ordinary process of flint-flaking, and asked those who believed Nature to have been responsible for these forms to produce, by some unguided natural force, flaked flints which would also simulate the true rostro-carinate type. This, however, they had, up to the present, been quite unable to do.

He dealt with the specimens exhibited by Prof. Sollas, and found by him on the beach at Selsey Bill. The speaker explained how, after a visit to this site, he had noticed that many of the flints there, which are apparently of different ages, were in process of disintegration, and were easily broken up by the waves. The fractures thus produced were entirely unlike those formed by human blows; and, though he was of opinion that some of the Selsey flints were humanly shaped, none of them showed the same form of flaking as the true rostro-carinate implements that were exhibited.

Regarding the geological position of the flints claimed to be of pre-Red Crag age, he wished it to be known that flaked specimens, of exactly the same order as those found first at Messrs. Bolton & Laughlin's pit, had now been found beneath undisturbed shelly Red Crag at Thorington Hall, the Back Hamlet (Ipswich), Greenwich Farm (Ipswich), Marblesham near Woodbridge, and at Sutton in East Suffolk.

The statement that the decalcified Crag at Messrs. Bolton & Laughlin's pit was undisturbed and in its original position, though supported by Mr. W. Whitaker and Dr. Marr, had been disputed by some Ipswich geologists; but the speaker persisted in holding the view that the Crag at this spot was *in situ*.

To anyone familiar with the sub-Crag flints, it was quite obvious that those found in Messrs. Bolton & Laughlin's pit could only have come from the sub-Crag detritus-bed. The suggestion that, because the London Clay at this pit had been contorted by pressure, this pressure had been able to act through the fine sand overlying

the flint-bed, appeared to the speaker to be opposed to the laws of physics and quite untenable.

Specimens of flaked flints were shown, having shelly Crag and barnacles of the Red-Crag Sea attached to their worked surfaces.

Mr. E. A. MARTIN wished to point out that primitive Man, when he began to use tools, probably made them of wood. When he became perfect in tool-making, he was able to fashion those finely-chipped implements the genuineness of which was unquestioned. There was of necessity an intermediate stage, when his attempts at flint-chipping were rudimentary and clumsy. Those who believed in Eoliths held the opinion that these were his first attempts.

Mr. S. H. WARREN said, with reference to remarks that had been made, that he must point out the extreme difficulty of working experimentally under conditions such as would come within Mr. Moir's definition of 'unguided natural force.' There were many natural products which it was by no means easy to reproduce experimentally. He felt that the only scientific attitude to hold, in regard to experiments with flints, was to use them as an investigation of the chipping properties of flint; and that the knowledge of flint-fracture so gained should be applied by careful comparison with the chipping of alleged human implements, and on the other hand with that which geologists also knew of the operation of mechanical forces in Nature.

Mr. P. G. H. BOSWELL said that, with regard to the so-called 'rostro-carinate' type of implements, the President's first question as to whether the geological horizon of the flints was certain, had not been discussed. The stratigraphical position of the large majority of chipped flints which were said to come from below the Red Crag was not certain; out of fifteen (presumably the best at that time) figured and described by Sir E. Ray Lankester,[1] no less than twelve were from either Messrs. Bolton & Laughlin's brickyard or the Hadleigh-Road pits, both at Ipswich. Each of these sites, on account of its position on the flank of the Gipping Valley, was intensely disturbed by glacial action, the London Clay, supposed Red-Crag débris, and Glacial sand, gravel, and clay being contorted and overthrust until the sequence was repeatedly inverted. Before discussing the question of the human or natural chipping of these supposed implements, it seemed highly desirable that geologists should insist upon ruling out all flints which had been obtained from glacially-disturbed deposits, and all those not actually taken *in situ* from below Red Crag. It might be mere coincidence, but it was a point worthy of note by those who insisted upon the natural chipping of flint, that the best implements had been obtained from two localities where ice-pressure had been intense upon valley-spurs, the beds being disturbed for some 40 feet in depth.

Again, the term 'Middle Glacial' had served a very useful purpose in the past, but the time had now arrived when the various Glacial deposits of East Anglia should be more clearly defined,

[1] Phil. Trans. Roy. Soc. ser. B, vol. ccii (1912) pp. 283–336.

especially when it was alleged that implements were found in them. At present, they were in the position in Suffolk of not knowing what was meant by 'Middle Glacial': in fact, there was a possibility that it did not exist. Various deposits of Upper Glacial and even post-Chalky Boulder-Clay age had been mapped under this name. Of what age, then, were the supposed implements from the 'Middle Glacial'?

Finally, the speaker wished to urge caution upon Suffolk archæologists, and pleaded that they should study carefully the elementary geology of their district before indulging in the misstatements which had been so frequent in recently-published archæological papers, and were in danger of bringing the science into disrepute.

In addition to the exhibits described on pp. ii–ix, the following specimens were shown:—

Stone from the Sinai Peninsula, 70 miles south of Suez and 3 miles from the sea, showing the effects of heat and frost, exhibited by T. Codrington, M.Inst.C.E., F.G.S.

Palæolith found in 1876 in the Glacial gravels of the Yare Valley, in the grounds of Oakland House, Cringleford, exhibited by F. W. Harmer, F.G.S.

Mousterian flint-implements from the Crayford brick-earths, exhibited by R. Brice Higgins.

December 3rd, 1913.

Dr. Aubrey Strahan, F.R.S., President,
in the Chair.

Louis Barrow, Wolverley, Middleton-Hall Road, King's Norton; Charles Bradshaw, F.C.S., Assistant Curator in the Sheffield Public Museum, 17 Crimicar Lane, Fulwood, Sheffield; Charles Andrew Cotton, M.Sc., Lecturer on Geology in Victoria College, Wellington (New Zealand); Sydney C. Harland, B.Sc., Mycologist & Geologist to the Agricultural Research Station, Christiansted, Santa Cruz (Danish West Indies); William Stevenson Laing, 12 Kirkhill Road, Edinburgh; Percy Gates Morgan, M.A., Director of the Geological Survey, Mines Department, Wellington (New Zealand); Frederick George Percival, B.Sc., Assistant Demonstrator in Geology, Royal College of Science, 31 Hestercombe Avenue, Fulham, S.W.; Edward Charles Rodda, Hathersage, Wilton Road, Shirley, Southampton; Alexander J. Sefi, Kashmir, Lydford Road, Cricklewood, N.W.; John G. Sutherland, M.A., Principal of the High School, Umtali (Southern Rhodesia); Charles Taylor Trechmann, B.Sc., Hudworth Tower, Castle Eden (County Durham); Leonard James Wild, M.A., Selwyn College, Dunedin

(New Zealand); and Sydney Wilkinson, B.A., Lecturer on Geography in the Normal College at Bangor, Hightown, Liversidge (Yorkshire), were elected Fellows of the Society.

The List of Donations to the Library was read.

Prof. E. HULL, in exhibiting a block of Lower Lias from the junction with the Carboniferous, said that this block was sent from No. 3 pit of Dover Colliery, by the Manager, Mr. John Kiers. It seemed to him (the speaker) a specimen of peculiar interest, since it had been taken from the bottom of the Lias at its junction with the Coal Measures, at a depth of 1161 feet below the surface. It consisted of hard, bluish, brecciated limestone, angular pebbles of stone being cemented together, and contained numerous fossils of Liassic species—generally in a fragmentary condition. It had been called by the miners a 'piece of the old shore'—an appropriate name; as it was evidently made up of fragments of stone which had been knocked about on the beach of the Liassic sea when being deposited on a shore of submerged Coal Measures.

Dr. F. L. Kitchin had informed him that this lowest Lias at Dover has been shown to belong to a position in the upper part of the *Capricornus* Zone; it has yielded *Ammonites maculatus* Young & Bird.[1] Dr. Kitchin had further remarked that the block now exhibited contains fossils which are, for the most part, not in a state favourable for determination. The belemnites are tightly embedded in the hard matrix, and those at the surface are broken across in various directions. He was unable to identify them. Of lamellibranch remains he could only name *Unicardium cardioides* Phillips. There are also present some Rhynchonellids, but Dr. Kitchin has not been able to determine them.

The following communications were read:—

1. 'A Contribution to our Knowledge of the Geology of the Kent Coalfield.'[2] By Dr. E. A. Newell Arber, M.A., F.L.S., F.G.S.

2. 'On the Fossil Floras of the Kent Coalfield.' By Dr. E. A. Newell Arber, M.A., F.L.S., F.G.S.

In addition to the exhibit described above, fossil plants from the Kent Coalfield and a specimen of coal from the Dover Colliery were exhibited by Dr. E. A. Newell Arber, M.A., F.L.S., F.G.S., in illustration of his papers.

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[1] See G. W. Lamplugh & F. L. Kitchin, 'Mesozoic Rocks in some of the Coal Explorations in Kent' Mem. Geol. Surv. 1911, p. 143.

[2] Withdrawn by permission of the Council.

December 17th, 1913.

Dr. AUBREY STRAHAN, F.R.S., President,
in the Chair.

Richard Morgan Evans, Lecturer on Mining & Geology in the Wigan Mining College, 6 Eccleston Street, Wigan; Richard Hugh Sennett, 32 Bolton Gardens, S.W.; and George P. Wight, Southlands, Heath Road, Hayward's Heath (Sussex), were elected Fellows of the Society.

The List of Donations to the Library was read.

Mr. C. DAWSON, in exhibiting specimens of zinc-blende from the upper beds of the Purbeck formation at Netherfield (Sussex), remarked that these specimens were obtained from an horizon which was stratigraphically not far beneath the horizon in the Fairlight Clays whence were derived the specimens of zinc-blende previously exhibited by him on June 25th, 1913.[1] Like the other, the Purbeck zinc-blende probably owed its origin to segregation from Primary and metamorphic rocks, of which both strata are partly composed. He claimed that this discovery indicates another link between the Hastings Beds and the Purbeck Series.

The following communication was read:—

'Supplementary Note on the Discovery of a Palæolithic Human Skull and Mandible at Piltdown (Sussex).' By Charles Dawson, F.S.A., F.G.S., and Arthur Smith Woodward, LL.D., F.R.S., Sec.G.S. With an Appendix by Prof. Grafton Elliot Smith, M.A., M.D., V.P.R.S.

In addition to the exhibit described above, the following specimens were exhibited:—

Fragments of *Eoanthropus dawsoni*, specimens of the gravel-bed at Piltdown in which it was found, with flints and pebbles from the same locality, exhibited by C. Dawson, F.S.A., F.G.S.

Plaster cast of the Mousterian skull from La Chapelle-aux-Saints, with cast of the brain-cavity of the same; and a plaster cast of the mandible of *Homo heidelbergensis*, both exhibited by Dr. A. Smith Woodward, F.R.S., Sec.G.S.

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[1] See Q. J. G. S. vol. lxix (1913) p. xcviii.

January 7th, 1914.

Dr. AUBREY STRAHAN, F.R.S., President,
in the Chair.

The List of Donations to the Library was read.

The following Fellows of the Society, nominated by the Council, were elected Auditors of the Society's Accounts for the preceding year: JAMES VINCENT ELSDEN, D.Sc., and SAMUEL HAZZLEDINE WARREN.

The following communications were read:—

1. 'The Ordovician and Silurian Rocks of the Lough-Nafooey Area (County Galway).' By Charles Irving Gardiner, M.A., F.G.S., and Sidney Hugh Reynolds, M.A., F.G.S., Professor of Geology in the University of Bristol.

2. 'The Geology of St. Tudwal's Peninsula (Carnarvonshire).' By Tressilian Charles Nicholas, B.A., F.G.S.

Specimens and microscope-sections of Ordovician and Silurian rocks from the Lough-Nafooey area were exhibited by C. I. Gardiner, M.A., F.G.S., and Prof. S. H. Reynolds, M.A., F.G.S., in illustration of their paper.

Specimens from the St. Tudwal's Peninsula were exhibited by T. C. Nicholas, B.A., F.G.S., in illustration of his paper.

January 21st, 1914.

Dr. AUBREY STRAHAN, F.R.S., President,
in the Chair.

Samuel Balcon, Schoolhouse, Sutton Coldfield; Frank Remington Pretyman, Assoc. R.S.M., Richmond Lodge, Bournemouth; and Sydney H. Houghton, B.A., Assistant in the Geological Department of the South African Museum, Cape Town, were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communications were read:—

1. 'Geology of the Country round Huntly (Aberdeenshire).' By William Robert Watt, M.A., B.Sc., F.G.S.

2. 'The Glacial Geology of East Lancashire.' By Albert Jowett, D.Sc., F.G.S.

Rock-specimens and microscope-slides were exhibited by W. R. Watt, M.A., B.Sc., F.G.S., in illustration of his paper.

Lantern-slides were exhibited by Dr. A. Jowett, F.G.S., in illustration of his paper.

The following maps were also exhibited:—

Geological Survey of Scotland: 1-inch scale, Sheet 82, Loch Carron (Ross-shire), presented by the Director of H.M. Geological Survey.

Royal Geological Institute of Hungary—Sheets Brusztura, Ökörmezö & Tuchla, and Dognacska & Gattaja, on the scale of 1:75,000, presented by the Director of that Institute.

Geological Map of Natal, 1910, on the scale of 20 miles to the inch, or 1:1,267,200, presented by the Natal Government.

February 4th, 1914.

Dr. Aubrey Strahan, F.R.S., President, in the Chair.

Gordon Willis Lepper, care of the Burma Oil Company, Ltd., Nyaunghla (Upper Burma), was elected a Fellow of the Society.

The List of Donations to the Library was read.

The following communications were read:—

1. 'The Lithology and Composition of Durham Magnesian Limestones.' By Charles Taylor Trechmann, B.Sc., F.G.S.

2. 'On the Occurrence of a Giant Dragon-Fly in the Radstock Coal Measures.' By Herbert Bolton, M.Sc., F.R.S.E., F.G.S.

Specimens from the Durham Magnesian Limestone were exhibited by C. T. Trechmann, B.Sc., F.G.S., in illustration of his paper.

Insects from the Radstock Coal Measures were exhibited by H. Bolton, M.Sc., F.R.S.E., F.G.S., in illustration of his paper.

The following geological maps were also exhibited:—

Carte Géologique Internationale de l'Europe: Sheets E 1, F 1, and G I–VII, on the scale of 1:1,500,000.—1913.

Geological Survey of the Union of South Africa: Sheet 2; Pienaars River, on the scale of 2·347 miles to the inch, or 1:156,500.—1913. Presented by the Director of that Survey.

ANNUAL GENERAL MEETING,

February 20th, 1914.

Dr. Aubrey Strahan, F.R.S., President,
in the Chair.

Report of the Council for 1913.

During the year under review 65 new Fellows were elected into the Society (2 more than in 1912). Of the 65 Fellows elected in 1913, 48 paid their Admission Fees before the end of that year. Of the Fellows who had been elected in the previous year, 17 paid their Admission Fees in 1913, making the total accession of new Fellows during the year under review amount to 65 (8 more than in 1912).

Deducting from this number a loss of 44 Fellows (17 resigned, 24 deceased, and 3 removed from the List, under Bye-Laws, Sect. VI, Art. 5), it will be seen that there is an increase of 21 in the number of Fellows (as compared with an increase of 5 in 1912 and a decrease of 5 in 1911).

The total Number of Fellows is, therefore, now 1320, made up as follows:—Compounders, 245 (2 less than in 1912); Contributing Fellows, 1057 (26 more than in 1912); and Non-Contributing Fellows, 18 (3 less than in 1912).

Turning to the Lists of Foreign Members and Foreign Correspondents, the Council recall with regret the loss during the past year of Prof. A. Baltzer, Prof. H. Credner, and Prof. A. Fritsch, Foreign Members; as also of Prof. Igino Cocchi, Foreign Correspondent. It will be remembered that there were three vacancies in the List of Foreign Correspondents at the end of 1912: two of these were subsequently filled by the election of Prof. Émile Haug and Dr. P. J. Holmquist. There now remain three vacancies in the List of Foreign Members and two in that of Foreign Correspondents.

With regard to the Income and Expenditure of the Society during 1913, the figures set forth in detail in the Balance-Sheet may be summarized as follows:—The actual Receipts (excluding the Balance of £641 2*s.* 3*d.* brought forward from the previous year) amounted to £3,367 8*s.* 11*d.*, being £219 8*s.* 11*d.* more than the estimated Income. On the other hand, the total Expenditure during the same year amounted to £3,137 12*s.* 1*d.*, being £10 7*s.* 11*d.* less than the estimated Expenditure for the year, and £229 16*s.* 10*d.* less than the actual Receipts, the year closing with a Balance in hand of £871 3*s.* 9*d.*

The Council have to announce the completion of Vol. LXIX (for 1913) of the Society's Journal. It is hoped that No. 19 of the Record of Geological Literature (for 1912) will be ready for publication early in the current year, and that No. 20 may also be issued within this year.

A successful and largely-attended Conversazione was held in the Society's Apartments on June 18th, 1913. During the past year these Apartments have been used for General or for Council Meetings by the Mineralogical Society, the Palæontographical Society, the Ray Society, the Geologists' Association, the British Association, the Institution of Mining & Metallurgy, the Institution of Mining Engineers, the Institution of Water Engineers, and the British Science Guild; also for sectional meetings by the International Congress of Historical Studies.

Improvements have been effected in the electric lighting arrangements in the Library; and the Council have considered a scheme for the ventilation of the Meeting Room, and have now called for specifications for the installation of an electric fan.

The retirement on pension of the former Assistant Librarian, Mr. William Rupert Jones, after 40 years' service, was sanctioned at a Special General Meeting on April 9th; and at the same meeting the appointment of Mr. Maurice St. John Hope as Assistant Clerk was confirmed by the Fellows. On April 23rd, the Council temporarily appointed Mr. Charles Panzetta Chatwin as Assistant Librarian, subject to confirmation by the Fellows at a Special General Meeting.

The President was nominated by the Council to represent the Society at the Meeting of the Twelfth International Geological Congress, held at Toronto in August last. The Council, on the understanding that an International Geological Map of the World was to be undertaken, agreed to be responsible for twenty-five copies, in the event of its publication, at a probable expenditure of not more than £31 5*s.* 0*d.* *per annum* for eight years.

The eleventh Award from the Daniel-Pidgeon Trust Fund was made on March 19th, 1913, to Roderick Urwick Sayce, B.A., University College of Wales, Aberystwyth, who proposed to investigate the rock-succession and structure of the Ystwyth Valley and its neighbourhood.

The following Awards of Medals and Funds have also been made by the Council:—

The Wollaston Medal is awarded to Dr. John Edward Marr, F.R.S., in recognition of his 'researches concerning the Mineral Structure of the Earth,' especially in connexion with the Stratigraphy of the Lower Palæozoic Rocks.

The Murchison Medal, together with a Sum of Ten Guineas from the Murchison Geological Fund, is awarded to Mr. William Augustus Edmond Ussher, in recognition of his valuable contributions to Geological Science, more especially in connexion with the Devonian Rocks.

The Lyell Medal, together with a Sum of Twenty-Five Pounds

from the Lyell Geological Fund, is awarded to Charles Stewart Middlemiss, B.A., as an acknowledgment of the value of his contributions to our knowledge of the Geology of India.

The Balance of the Proceeds of the Wollaston Donation Fund is awarded to Mr. Richard Bullen Newton, in recognition of the value of his researches in the Palæontology of the Invertebrata, especially the Mollusca.

The Balance of the Proceeds of the Murchison Geological Fund is awarded to Mr. Frederick Nairn Haward, in acknowledgment of his researches on the Fracturing of Flint.

A moiety of the Balance of the Proceeds of the Lyell Geological Fund is awarded to the Rev. Walter Howchin, in recognition of the value of his contributions to our knowledge of a glacial episode of Cambrian age in Australia.

A second moiety of the Balance of the Proceeds of the Lyell Geological Fund is awarded to Mr. John Postlethwaite, in acknowledgment of his researches in the Geology of the Lake District.

Report of the Library Committee for 1913.

The Committee have pleasure in reporting that the Additions made to the Society's Library during the past year have fully maintained, both in number and in importance, the standard of previous years.

During 1913 the Library received by Donation 50 Volumes of separately published Works, 293 Pamphlets, and 65 detached Parts of Works; also 375 Volumes and 21 detached Parts of Serial Publications, 146 Volumes and 98 detached Parts of the publications of Geological Surveys and other public bodies, and 25 Volumes of Weekly Periodicals.

The total number of accessions to the Library by Donation is thus seen to amount to 596 Volumes, 293 Pamphlets, and 184 detached Parts. In addition, 37 Sheets of Geological Maps were presented to the Library, including 6 Sheets received from the Geological Survey of England & Wales, and 18 from that of Scotland; 5 Sheets from the Geological Survey of Japan; 3 Sheets from the Geological Survey of the Union of South Africa; 2 Sheets from that of Hesse-Darmstadt; and 1 Sheet each from the Geological Surveys of Russia, French Indo-China, and Victoria.

Among the Books and Pamphlets mentioned in the foregoing paragraph, especial attention may be directed to the following works:—the 2nd volume of the 5th edition of Prof. E. Kayser's 'Lehrbuch der Geologie'; the 2nd volume of Prof. J. P. Idding's 'Igneous Rocks'; the 5th volume of Prof. A. Lacroix's 'Minéralogie de la France & de ses Colonies'; Prof. T. G. Bonney's 'Building of the Alps'; Prof. J. W. Gregory's 'Nature & Origin

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of Fiords'; Dr. C. D. Walcott's monograph on the Cambrian Brachiopoda; Dr. F. R. C. Reed's monograph on the Ordovician & Silurian Fossils of the Central Himalayas; Mr. H. M. Cadell's 'Story of the Forth'; and the second volume of the 'Text-Book of Petrology (the Sedimentary Rocks),' by Dr. F. H. Hatch & Mr. R. H. Rastall; the Geological Survey Memoirs on the Geology of the Country around Winchester & Stockbridge, on the Geology of Dartmoor, on the Geology of the Country around Ivybridge & Modbury, on the Concealed Coalfield of Yorkshire & Nottinghamshire, on the Geology of the Country around Newton Abbot, on the Geology of Ben Wyvis, Cairn Chuinneag, etc. on the Geology of Upper Strathspey, Gaick, & the Forest of Atholl, and on the Geology of the Fannich Mountains, etc. as also the 'Records of London Wells.' Three British Museum (Natural History) Catalogues were received during the year: namely, those of the Marine Reptiles of the Oxford Clay (part 2), of the Cretaceous Plants, and of the Living & Fossil Species of *Pisidium*.

In addition, numerous publications were received from the Departments of Mines and Geological Survey Departments of the Dominion of Canada, of the Provinces of Ontario and British Columbia, of the Provinces of the Cape of Good Hope and the Transvaal, of the various States of the Commonwealth of Australia, and of the Dominion of New Zealand; also from the Geological Survey Departments of India, Mysore, Egypt, the Sudan, Belgium, Holland, Italy, Portugal, Hungary, Bohemia, Russia, and Norway; from the United States Geological Survey, and from the independent State Surveys of Alabama, Illinois, Iowa, New York, Ohio, and Oklahoma. Series of valuable Reports were presented by the Colonial Office and the Home Office.

The Books and Maps enumerated in the foregoing paragraphs were the gift of 156 Government Departments and other Public Bodies; of 181 Societies and Editors of Periodicals; and of 156 Personal Donors.

The Purchases, made on the recommendation of the standing Library Committee, included 38 Volumes and 50 detached Parts of separately published Works, and 38 Volumes and 27 detached Parts of Works published serially.

The Expenditure incurred in connexion with the Library during the year under review was as follows:—

	£	s.	d.
Books, Periodicals, etc. purchased	102	18	8
Binding of Books and Mounting of Maps...	122	5	11
Total................	£225	4	7

The retirement on pension of the former Assistant Librarian in May, and the much-needed reorganization of the Library have necessarily delayed the preparation of the Record of Geological

Literature received in 1912, but the work is making satisfactory progress.

During the year Mr. W. Campbell Smith, F.G.S., has kindly volunteered his services in helping to put the Society's Map Collection in order, and he has already spent a considerable time over that work. The Society is greatly indebted to him for this assistance.

Mr. C. Davies Sherborn reports that

'The Card Catalogue makes satisfactory progress. Editing has now commenced, and the cards are in completed arrangement up to BR (the first fifty drawers). This editing has considerably reduced the bulk of the cards, thus allowing the calculated space for accessions for some years to come. I may point out that, if the searcher will refer to the footnotes of those books to which the Card Catalogue refers him, he will now be in possession of an almost complete bibliography of any subject desired.

'I also hope that the literature for 1883–1893 will be taken in hand this year, as that is the only gap now remaining between 1800 and 1912.'

The appended Lists contain the Names of Government Departments, Public Bodies, Societies, Editors, and Personal Donors, from whom Donations to the Library have been received during the year under review:—

I. Government Departments and other Public Bodies.

Alabama.—Geological Survey. Montgomery (Ala.).
American Museum of Natural History. New York.
Anglo-Egyptian Sudan.—Geological Survey. Khartûm.
Argentina.—Ministerio de Agricultura. Buenos Aires.
Australia (S.), etc. *See* South Australia, *etc.*
Austria.—Kaiserlich-Königliche Geologische Reichsanstalt. Vienna.
Bavaria.—Königliches Bayerisches Oberbergamt. Munich.
Belgium.—Académie Royale des Sciences, des Lettres & Beaux-Arts de Belgique, Brussels.
——. Musée du Congo Belge. Brussels.
——. Musée Royal d'Histoire Naturelle. Brussels.
——. Service Géologique de Belgique. Brussels.
Bergens Museum. Bergen.
Berlin.—Königliche Preussische Akademie der Wissenschaften.
Birmingham, University of.
Bohemia.—Naturwissenschaftliche Landesdurchforschung. Prague.
——. Royal Museum of Natural History. Prague.
Bristol.—Museum & Art Gallery.
British Columbia.—Department of Mines. Victoria (B.C
British Guiana.—Department of Mines. Georgetown.
British South Africa Company. London.
Bucarest.—Museului de Geologia si de Paleontologia.
Buenos Aires.—Museo Nacional de Buenos Aires.
California.—Academy of Sciences. San Francisco.
——, University of. Berkeley (Cal.).
Camborne.—Mining School.

Cambridge.—Sedgwick Museum.
Cambridge (Mass.).—Museum of Comparative Zoology in Harvard College.
Canada.—Geological & Natural History Survey. Ottawa.
——, High Commissioner for. London.
Cape of Good Hope.—South African Museum. Cape Town.
Carinthia.—Government Mining Bureau. Raibl.
Chicago.—'Field' Columbian Museum.
Connecticut.—State Geological & Natural History Survey. Hartford (Conn.).
Córdoba (Argentine Republic).—Academía Nacional de Ciencias.
Cracow.—Academy of Sciences.
Denmark.—Commission for Ledelsen af de Geologiske & Geographiske Undersögelser i Grönland. Copenhagen.
——. Geologiske Undersögelse. Copenhagen.
——. Kongelige Danske Videnskabernes Selskab. Copenhagen.
Dublin.—Royal Irish Academy.
Egypt.—Department of Public Works (Survey Department). Cairo.
Finland.—Finlands Geologiska Undersökning. Helsingfors.
France.—Ministère de la Guerre. Paris.
——. Ministère des Colonies. Paris.
——. Ministère des Travaux Publics. Paris.
——. Muséum d'Histoire Naturelle. Paris.
Geneva, University of.
Georgia.—Geological Survey.
Germany.—Kaiserliche Leopoldinisch-Carolinische Deutsche Akademie der Naturforscher. Halle an der Saale.
Great Britain.—British Museum (Natural History). London.
——. Colonial Office. London.
——. Geological Survey. London.
——. Home Office. London.
——. India Office. London.
Holland.—Departement van Kolonien. The Hague.
——. Rijksopsporing van Delfstoffen. The Hague.
Hull.—Municipal Museum.
Hungary.—Königliche Ungarische Geologische Anstalt (Magyar Földtani Tarsulat). Budapest.
Illinois State Geological Survey. Urbana (Ill.).
India.—Geological Survey. Calcutta.
——. Indian Museum. Calcutta.
——. Surveyor-General's Office. Calcutta.
Iowa Geological Survey. Des Moines (Iowa).
Ireland.—Department of Agriculture & Technical Instruction. Dublin.
Italy.—Reale Comitato Geologico. Rome.
Japan.—Earthquake-Investigation Committee. Tokyo.
——. Geological Survey. Tokyo.
Jassy, University of.
Kansas.—University Geological Survey. Lawrence (Kan.).
Kingston (Canada).—Queen's College.
Klausenburg (Koloszvár).—Provincial Museum & Library.
Leeds, University of.
London.—City of London College.
——. Imperial College of Science & Technology.
——. Imperial Institute.
——. Metropolitan Water Board.
——. Royal College of Surgeons.
——. University College.
Madrid.—Real Academía de Ciencias Exactas, Físicas & Naturales.
Magdeburg.—Museum für Natur- und Heimatkunde.
Maryland.—Geological Survey. Baltimore (Md.).
Melbourne (Victoria).—National Museum.
Mexico.—Instituto Geológico. Mexico City.
Milan.—Reale Istituto Lombardo di Scienze & Lettere.
Missouri.—Bureau of Geology & Mines. Rolla (Mo.).
Montana University. Missoula (Mont.).
Munich.—Königliche Bayerische Akademie der Wissenschaften.
Mysore Geological Department. Bangalore.
Nancy.—Académie de Stanislas.
Naples.—Accademia delle Scienze.

New Jersey.—Geological Survey. Trentham (N.J.).
New Mexico, University of. Albuquerque (N. Mex.).
New South Wales, Agent-General for. London.
——. Department of Mines & Agriculture. Sydney.
——. Geological Survey. Sydney.
New York State Museum. Albany (N.Y.).
New Zealand.—Department of Mines. Wellington.
——. Geological Survey. Wellington.
Norway.—Norges Geologiske Undersökelse. Christiania.
Nova Scotia.—Department of Mines. Halifax.
Ohio Geological Survey. Columbus (Ohio).
Oklahoma Geological Survey. Norman (Okla.).
Ontario.—Bureau of Mines. Toronto.
Padua.—Reale Accademia di Scienze, Lettere & Arti.
——, University of.
Paris.—Académie des Sciences.
Perak Government. Taiping.
Peru.—Ministerio de Fomento. Lima.
Philippine Is.—Department of the Interior: Bureau of Science. Manila.
Pisa, Royal University of.
Portici.—Reale Scuola Superiore di Agricoltura.
Portugal.—Commissão dos Trabalhos Geologicos. Lisbon.
Prussia.—Königliches Ministerium für Handel & Gewerbe (Zeitschrift für das Berg- Hütten- & Salinenwesen). Berlin.
——. Königliche Preussische Geologische Landesanstalt. Berlin.
Queensland, Agent-General for. London.
——. Department of Mines. Brisbane.
——. Geological Survey. Brisbane.
Redruth.—School of Mines.
Rhodesia.—Chamber of Mines. Bulawayo.
Rhodesian Museum. Bulawayo.
Rio de Janeiro.—Museu Nacional.
Rome.—Reale Accademia dei Lincei.
Rumania.—Geological Survey. Bucarest.
Russia.—Comité Géologique. St. Petersburg.
——. Musée Géologique Pierre le Grand. St. Petersburg.
——. Section Géologique du Cabinet de S.M. l'Empereur. St. Petersburg.
São Paulo (Brazil).—Commissão Geographica & Geologica. São Paulo City.
——. Secretaria da Agricultura, Commercio & Obras Publicas. São Paulo City.
Sarawak Museum. Singapore.
Sendai (Japan).—Tohoku Imperial University.
South Africa, Union of.—Department of Mines. (Geological Survey, etc.) Pretoria.
South Australia, Agent-General for. London.
——. Department of Mines. Adelaide.
——. Geological Survey. Adelaide.
Spain.—Comision del Mapa Geológico. Madrid.
Stockholm.—Kongliga Svenska Vetenskaps Akademi.
Sweden.—Sveriges Geologiska Undersökning. Stockholm.
Switzerland.—Geologische Kommission der Schweiz. Berne.
Tasmania.—Secretary for Mines. Hobart.
Tokyo.—College of Science (Imperial University).
Transylvania.—National Museum: Geological & Mineralogical Department. Hermannstadt.
Turin.—Reale Accademia delle Scienze.
Union of South Africa. *See* South Africa.
United States.—Department of Agriculture. Washington (D.C.).
——. Geological Survey. Washington (D.C.).
——. National Museum. Washington (D.C.).
Upsala, Royal University of.
Victoria (Austral.), Agent-General for. London.
—— (——). Department of Mines. Melbourne.
—— (——). Geological Survey. Melbourne.
Vienna.—Kaiserliche Akademie der Wissenschaften.
Washington (D.C.).—Smithsonian Institution.
Washington, State of (U.S.A.).—Geological Survey. Olympic (Wash.).

Western Australia, Agent-General for. London.
——. Department of Mines. Perth.
——. Geological Survey. Perth.
——. Museum & Art Gallery. Perth.
Wisconsin.—Geological & Natural History Survey. Madison (Wisc.).
Yale University Museum (Peabody Museum). Geological Department. New Haven (Conn.).

II. Societies and Editors.

Acireale.—Accademia di Scienze, Lettere & Arti.
Adelaide.—Royal Society of South Australia.
Agram.—Societas Historico-Naturalis Croatica.
Basel.—Naturforschende Gesellschaft.
Bath.—Natural History & Antiquarian Field-Club.
Belgrade.—Servian Geological Society.
Bergen.—'Naturen.'
Berlin.—Deutsche Geologische Gesellschaft.
——. Gesellschaft Naturforschender Freunde.
——. Institut für Meereskunde & Geographisches Institut.
——. 'Zeitschrift für Praktische Geologie.'
Berne.—Schweizerische Naturforschende Gesellschaft.
Bombay Branch of the Royal Asiatic Society.
Bordeaux.—Société Linnéenne.
Boston (Mass.) Society of Natural History.
——. American Academy of Arts & Sciences.
Bristol Naturalists' Society.
Brooklyn (N.Y.) Institute of Arts & Sciences.
Brunswick.—Verein für Naturwissenschaft zu Braunschweig.
Brussels.—Société Belge de Géologie, de Paléontologie & d'Hydrologie.
——. Société Royale Zoologique & Malacologique de Belgique.
Budapest.—Földtani Közlöny.
Buenos Aires.—Sociedad Científica Argentina.
Bulawayo.—Rhodesian Scientific Association.
Caen.—Société Linnéenne de Normandie.
Calcutta.—Asiatic Society of Bengal.
Cambridge Philosophical Society.
Cape Town.—Royal Society of South Africa.
——. South African Association for the Advancement of Science.
Cardiff.—South Wales Institute of Engineers.
Chambéry.—Société d'Histoire Naturelle de Savoie.
Chicago.—'Journal of Geology.'
Christiania.—'Nyt Magazin for Naturvidenskaberne.'
Colombo.—Ceylon Branch of the Royal Asiatic Society.
Colorado Springs.—'Colorado College Studies.'
Croydon Natural History & Scientific Society.
Denver.—Colorado Scientific Society.
Dijon.—Académie des Sciences, Arts & Belles-Lettres.
Dorchester.—Dorset Natural History & Antiquarian Field-Club.
Dorpat (Jurjew).—Naturforschende Gesellschaft.
Dresden.—Naturwissenschaftliche Gesellschaft.
——. Verein für Erdkunde.
Edinburgh.—Geological Society.
——. Royal Physical Society.
——. Royal Scottish Geographical Society.
——. Royal Society.
Ekaterinburg.—Société Ouralienne d'Amateurs des Sciences Naturelles.
Falmouth.—Royal Cornwall Polytechnic Society.
Frankfurt am Main.—Senckenbergische Naturforschende Gesellschaft.
Freiburg im Breisgau.—Naturforschende Gesellschaft.
Fribourg.—Société Fribourgeoise des Sciences Naturelles.
Geneva.—Société de Physique & d'Histoire Naturelle.
Giessen.—Oberhessische Gesellschaft für Natur- & Heilkunde.
Glasgow.—Geological Society.
Gloucester.—Cotteswold Naturalists' Field-Club.

Gratz.—Naturwissenschaftlicher Verein für Steiermark.
Haarlem.—Société Hollandaise des Sciences.
Halifax (N.S.).—Nova Scotian Institute of Science.
Hamilton (Canada).—Hamilton Scientific Association.
Hanau.—Wetterauische Gesellschaft für Gesammte Naturkunde.
Havre.—Société Géologique de Normandie.
Helsingfors.—Société Géographique de Finlande.
Hereford.—Woolhope Naturalists' Field-Club.
Hermannstadt.—Siebenbürgischer Verein für Naturwissenschaft.
Hertford.—Hertfordshire Natural History Society.
Hull Geological Society.
Indianapolis (Ind.).—Indiana Academy of Science.
Johannesburg.—Geological Society of South Africa.
Kiev.—Société des Naturalistes.
Lancaster (Pa.).—'Economic Geology.'
Lausanne.—Société Vaudoise des Sciences Naturelles.
Leeds.—Philosophical & Literary Society.
——. Yorkshire Geological Society.
Leicester Literary & Philosophical Society.
Leipzig.—'Zeitschrift für Krystallographie & Mineralogie.
Liége.—Société Géologique de Belgique.
——. Société Royale des Sciences.
Lille.—Société Géologique du Nord.
Lima.—'Revista de Ciencias.'
Lisbon.—Sociedade de Geographia.
——. Société Portugaise des Sciences Naturelles.
Liverpool Geological Society.
——. Literary & Philosophical Society.
London.—'The Athenæum.'
——. British Association for the Advancement of Science.
——. Chemical Society.
——. 'The Chemical News.'
——. 'The Colliery Guardian.'
——. 'The Geological Magazine.'
——. Geologists' Association.
——. Institution of Civil Engineers.
——. Institution of Mining Engineers.
——. Institution of Mining & Metallurgy.
——. Institution of Water Engineers.
——. Iron & Steel Institute.
——. Linnean Society.
——. 'The London, Edinburgh, & Dublin Philosophical Magazine.'
——. Mineralogical Society.
——. 'The Mining Journal.'
——. 'Nature.'
——. Palæontographical Society.
——. Prehistoric Society of East Anglia.
——. 'The Quarry.'
——. Ray Society.
——. Records of the London & West-Country Chamber of Mines.
——. Royal Geographical Society.
——. Royal Institution.
——. Royal Meteorological Society.
——. Royal Microscopical Society.
——. Royal Photographic Society.
——. Royal Society.
——. Royal Society of Arts.
——. Society of Biblical Archæology.
——. 'The South-Eastern Naturalist' (S.E. Union of Scientific Societies).
——. Victoria Institute.
——. 'Water.'
——. Zoological Society.
Manchester Geological & Mining Society.
——. Literary & Philosophical Society.
Melbourne (Victoria).—Australasian Institute of Mining Engineers.
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——. 'The Victorian Naturalist.'

Mexico.—Sociedad Científica 'Antonio Alzate.'
Moscow.—Société Impériale des Naturalistes.
Newcastle-upon-Tyne.—North of England Institute of Mining & Mechanical Engineers.
——. University of Durham Philosophical Society.
New Haven (Conn.).—Academy of Arts & Sciences.
——. 'The American Journal of Science.'
New York.—Academy of Sciences.
——. American Institute of Mining Engineers.
——. 'Science.'
Northampton.—Northamptonshire Natural History Society.
Nürnberg.—Naturhistorische Gesellschaft.
Oporto.—Academia Polytecnica. [Coimbra.]
Ottawa.—Royal Society of Canada.
Paris.—Commission Française des Glaciers.
——. Société Française de Minéralogie.
——. Société Géologique de France.
——. 'Spelunca.'
Penzance.—Royal Geological Society of Cornwall.
Perth.—Perthshire Society of Natural Science.
Philadelphia.—Academy of Natural Sciences.
——. American Philosophical Society.
Pisa.—Società Toscana di Scienze Naturali.
Plymouth.—Devonshire Association for the Advancement of Science.
Portland Society of Natural History. Portland (Maine).
Rennes.—Société Scientifique & Médicale de l'Ouest.
Rochester (N.Y.).—Academy of Science.
——. Geological Society of America.
Rome.—Società Geologica Italiana.
Rugby School Natural History Society.
San Diego (Cal.).—Society of Natural History.
Santiago de Chile.—Sociedad Nacional de Minería.
——. Société Scientifique du Chili.
São Paulo (Brazil).—Sociedade Scientifica.
Scranton (Pa.).—'Mines & Minerals.'
St. John (N.B.).—Natural History Society of New Brunswick.
St. Petersburg.—Russische Kaiserliche Mineralogische Gesellschaft.
Stockholm.—Geologiska Förening.
Stratford.—Essex Field-Club.
Stuttgart.—'Centralblatt für Mineralogie, Geologie & Paläontologie.'
——. 'Neues Jahrbuch für Mineralogie, Geologie & Paläontologie.'
——. Oberrheinischer Geologischer Verein.
——. Verein für Vaterländische Naturkunde in Württemberg.
——. 'Zeitschrift für Naturwissenschaften.'
Swansea.—Royal Institution of South Wales.
Sydney (N.S.W.).—Linnean Society of New South Wales.
——. Royal Society of New South Wales.
Toronto.—Canadian Institute.
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Vienna.—'Beiträge zur Paläontologie & Geologie Œsterreich-Ungarns & des Orients.'
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Comparative Statement of the Number of the Society at the Close of the Years 1912 and 1913.

	Dec. 31st, 1912.		Dec. 31st, 1913.
Compounders	247	....	245
Contributing Fellows	1031	....	1057
Non-Contributing Fellows	21	....	18
	1299		1320
Foreign Members	40	....	37
Foreign Correspondents	37	....	38
	1376		1395

Comparative Statement, explanatory of the Alterations in the Number of Fellows, Foreign Members, and Foreign Correspondents at the close of the Years 1912 and 1913.

Number of Compounders, Contributing, and Non-Contributing Fellows, December 31st, 1912 ...		1299
Add Fellows elected during the former year and paid in 1913		17
Add Fellows elected and paid in 1913		48
		1364
Deduct Compounders deceased	7	
Non-Contributing Fellows deceased	3	
Contributing Fellows deceased	14	
Contributing Fellows resigned	17	
Contributing Fellows removed	3	
	—	44
		1320
Number of Foreign Members and Foreign Correspondents, December 31st, 1912	77	
Deduct Foreign Members (3) and Foreign Correspondent (1) deceased	4	
	73	
Add Foreign Correspondents elected	2	
	—	75
		1395

Deceased Fellows.

Compounders (7).

Anderson, Dr. T.
Avebury, Lord.
Brogden, H.
Jamieson, T. F.
Milne, Dr. J.
Parsons, Dr. H. F.
Sclater, Dr. P. L.

Non-contributing Fellows (3).

Hobbins, Dr. J.
Lamont, Sir James.
Mitchell, F. J.

Resident and other Contributing Fellows (14).

Barnes, F. J.
Bell, S. N.
Canham, the Rev. H.
Churchward, W. G.
Coombs, J. A.
Cope, T. H.
Foote, R. B.
Gwinnell, R. F.
Habershon, M. H. H.
Lobley, J. L.
Mitchell, Dr. A.
Slater, H. K.
Sutcliffe, W. H.
Wilkins, T.

Fellows Resigned (17).

Brown, H. Y. L.
Cullis, F. J.
Fowler, the Rev. J.
Fox, W.
Heal, J. H.
Hodgkinson, Prof. W. R. E.
Leeson, Dr. J. R.
McKay, A.
McPherson, W.
Moreing, C. A.
Palk, D. S.
Simpson, A.
Slater, G.
Smith, G. Hildick.
Swain, E.
Turner, R. D.
Wilkinson, F.

Fellows Removed (3).

Birks, the Rev. J.
Green, G. A.
Mills, M. H.

The following Personages were elected Foreign Correspondents during the year 1913 :—

Dr. Émile Haug, of Paris.

Dr. Per Johan Holmquist, of Stockholm.

After the Reports had been read, it was resolved :—

That they be received and entered on the Minutes of the Meeting, and that such parts of them as the Council shall think fit be printed and circulated among the Fellows.

It was afterwards resolved :—

That the thanks of the Society be given to Dr. A. Strahan, the retiring President; to Dr. A. S. Woodward, the retiring Secretary; to Prof. E. J. Garwood, Mr. R. D. Oldham, and Prof. W. W. Watts, the retiring Vice-Presidents (all three retiring also from the Council); and to the other retiring Members of Council: Dr. G. T. Prior and Dr. A. Vaughan.

After the Balloting-Glasses had been closed, and the Lists examined by the Scrutineers, the following gentlemen were declared to have been duly elected as the Officers and Council for the ensuing year :—

OFFICERS AND COUNCIL.—1914.

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Arthur Smith Woodward, LL.D., F.R.S., F.L.S.

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William Hill.
Clement Reid, F.R.S., F.L.S.
Aubrey Strahan, Sc.D., LL.D., F.R.S.

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Herbert Lapworth, D.Sc., M.Inst.C.E.

FOREIGN SECRETARY.

Sir Archibald Geikie, O.M., K.C.B., D.C.L., LL.D., Sc.D., F.R.S.

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Herbert Henry Thomas, Sc.D., B.Sc.
William Whitaker, B.A., F.R.S.
The Rev. Henry Hoyte Winwood, M.A.
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LIST OF

THE FOREIGN MEMBERS

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Date of Election.

1877. Prof. Eduard Suess, *Vienna.*
1884. Commendatore Prof. Giovanni Capellini, *Bologna.*
1885. Prof. Jules Gosselet, *Lille.*
1886. Prof. Gustav Tschermak, *Vienna.*
1890. Geheimrath Prof. Heinrich Rosenbusch, *Heidelberg.* (*Deceased.*)
1891. Prof. Charles Barrois, *Lille.*
1893. Prof. Waldemar Christofer Brögger, *Christiania.*
1893. Prof. Alfred Gabriel Nathorst, *Stockholm.*
1894. Prof. Edward Salisbury Dana, *New Haven, Conn.* (*U.S.A.*).
1895. Dr. Grove Karl Gilbert, *Washington, D.C.* (*U.S.A.*).
1896. Prof. Albert Heim, *Zürich.*
1897. Dr. Hans Reusch, *Christiania.*
1898. Dr. Charles Doolittle Walcott, *Washington, D.C.* (*U.S.A.*).
1899. Prof. Emanuel Kayser, *Marburg.*
1899. M. Ernest Van den Broeck, *Brussels.*
1900. M. Gustave F. Dollfus, *Paris.*
1900. Prof. Paul von Groth, *Munich.*
1900. Dr. Sven Leonhard Törnquist, *Lund.*
1901. M. Alexander Petrovich Karpinsky, *St. Petersburg.*
1901. Prof. Alfred Lacroix, *Paris.*
1903. Prof. Albrecht Penck, *Berlin.*
1903. Prof. Anton Koch, *Budapest.*
1904. Prof. Joseph Paxson Iddings, *Brinklow, Maryland* (*U.S.A.*).
1904. Prof. Henry Fairfield Osborn, *New York* (*U.S.A.*).
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1907. Commendatore Prof. Arturo Issel, *Genoa.*
1908. Prof. Bundjirô Kôtô, *Tokyo.*
1908. Dr. Feodor Chernyshev, *St. Petersburg.* (*Deceased.*)
1909. Prof. Johan H. L. Vogt, *Christiania.*
1909. Prof. René Zeiller, *Paris.*
1911. Prof. Baron Gerard Jakob de Geer, *Stockholm.*
1911. M. Emmanuel de Margerie, *Paris.*
1912. Prof. Marcellin Boule, *Paris.*
1912. Prof. Johannes Walther, *Halle an der Saale.*

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THE FOREIGN CORRESPONDENTS

OF THE GEOLOGICAL SOCIETY OF LONDON, IN 1913.

Date of Election.

1879. Dr. H. Émile Sauvage, *Boulogne-sur-Mer.*
1889. Dr. Rogier Diederik Marius Verbeek, *The Hague.*
1890. Geheimer Bergrath Prof. Adolph von Kœnen, *Göttingen.*
1892. Prof. Johann Lehmann, *Weimar.*
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1893. M. Ed. Rigaux, *Boulogne-sur-Mer.*
1894. Dr. Francisco P. Moreno, *La Plata.*
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1911. Prof. Charles Depéret, *Lyons.*
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1912. Prof. Fusakichi Omori, *Tokyo.*
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1913. Dr. Per Johan Holmquist, *Stockholm.*

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ESTABLISHED BY

WILLIAM HYDE WOLLASTON, M.D., F.R.S., F.G.S., ETC.

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1912. Mr. Charles Irving Gardiner.
1913. Mr. William Wickham King.
1914. Mr. Richard B. Newton.

AWARDS OF THE MURCHISON MEDAL

UNDER THE CONDITIONS OF THE

'MURCHISON GEOLOGICAL FUND,'

ESTABLISHED UNDER THE WILL OF THE LATE

SIR RODERICK IMPEY MURCHISON, Bart., F.R.S., F.G.S.

'To be applied in every consecutive year, in such manner as the Council of the Society may deem most useful in advancing Geological Science, whether by granting sums of money to travellers in pursuit of knowledge, to authors of memoirs, or to persons actually employed in any enquiries bearing upon the science of Geology, or in rewarding any such travellers, authors, or other persons, and the Medal to be given to some person to whom such Council shall grant any sum of money or recompense in respect of Geological Science.'

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1874. Dr. J. J. Bigsby.
1875. Mr. W. J. Henwood.
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1878. Prof. Hanns Bruno Geinitz.
1879. Sir Frederick M'Coy.
1880. Mr. Robert Etheridge.
1881. Sir Archibald Geikie.
1882. Prof. Jules Gosselet.
1883. Prof. H. R. Gœppert.
1884. Dr. Henry Woodward.
1885. Dr. Ferdinand von Rœmer.
1886. Mr. William Whitaker.
1887. The Rev. Peter B. Brodie.
1888. Prof. J. S. Newberry.
1889. Prof. James Geikie.
1890. Prof. Edward Hull.
1891. Prof. Waldemar C. Brögger.
1892. Prof. A. H. Green.
1893. The Rev. Osmond Fisher.
1894. Mr. William T. Aveline.
1895. Prof. Gustaf Lindström.
1896. Mr. T. Mellard Reade.
1897. Mr. Horace B. Woodward.
1898. Mr. Thomas F. Jamieson.
1899. {Dr. Benjamin Neeve Peach. / Dr. John Horne.}
1900. Baron A. E. Nordenskiöld.
1901. Mr. A. J. Jukes-Browne.
1902. Mr. Frederic W. Harmer.
1903. Dr. Charles Callaway.
1904. Prof. George A. Lebour.
1905. Mr. Edward John Dunn.
1906. Mr. Charles T. Clough.
1907. Mr. Alfred Harker.
1908. Prof. Albert Charles Seward.
1909. Prof. Grenville A. J. Cole.
1910. Prof. Arthur Philemon Coleman.
1911. Mr. Richard Hill Tiddeman.
1912. Prof. Louis Dollo.
1913. Mr. George Barrow.
1914. Mr. William A. E. Ussher.

AWARDS

OF THE

BALANCE OF THE PROCEEDS OF THE 'MURCHISON GEOLOGICAL FUND.'

1873. Prof. Oswald Heer.
1874. { Mr. Alfred Bell.
Prof. Ralph Tate.
1875. Prof. H. Govier Seeley.
1876. Dr. James Croll.
1877. The Rev. John F. Blake.
1878. Prof. Charles Lapworth.
1879. Mr. James Walker Kirkby.
1880. Mr. Robert Etheridge.
1881. Mr. Frank Rutley.
1882. Prof. Thomas Rupert Jones.
1883. Dr. John Young.
1884. Mr. Martin Simpson.
1885. Mr. Horace B. Woodward.
1886. Mr. Clement Reid.
1887. Dr. Robert Kidston.
1888. Mr. Edward Wilson.
1889. Prof. Grenville A. J. Cole.
1890. Mr. Edward B. Wethered.
1891. The Rev. Richard Baron.
1892. Mr. Beeby Thompson.
1893. Mr. Griffith John Williams.
1894. Mr. George Barrow.
1895. Prof. Albert Charles Seward.
1896. Mr. Philip Lake.
1897. Mr. S. S. Buckman.
1898. Miss Jane Donald.
1899. Mr. James Bennie.
1900. Mr. A. Vaughan Jennings.
1901. Mr. Thomas S. Hall.
1902. Sir Thomas H. Holland.
1903. Mrs. Elizabeth Gray.
1904. Dr. Arthur Hutchinson.
1905. Prof. Herbert L. Bowman.
1906. Dr. Herbert Lapworth.
1907. Dr. Felix Oswald.
1908. Miss Ethel Gertrude Skeat.
1909. Dr. James Vincent Elsden.
1910. Mr. John Walker Stather.
1911. Mr. Edgar Sterling Cobbold.
1912. Dr. Arthur Morley Davies.
1913. Mr. Ernest Edward Leslie Dixon.
1914. Mr. Frederick Nairn Haward.

AWARDS OF THE LYELL MEDAL

UNDER THE CONDITIONS OF THE

'LYELL GEOLOGICAL FUND,'

ESTABLISHED UNDER THE WILL AND CODICIL OF THE LATE

SIR CHARLES LYELL, BART., F.R.S., F.G.S.

The Medal 'to be cast in bronze and to be given annually' (or from time to time) 'as a mark of honorary distinction and as an expression on the part of the governing body of the Society that the Medallist (who may be of any country or either sex) has deserved well of the Science,'—'not less than one third of the annual interest [of the fund] to accompany the Medal, the remaining interest to be given in one or more portions, at the discretion of the Council, for the encouragement of Geology or of any of the allied sciences by which they shall consider Geology to have been most materially advanced, either for travelling expenses or for a memoir or paper published, or in progress, and without reference to the sex or nationality of the author, or the language in which any such memoir or paper may be written.'

There is a further provision for suspending the award for one year, and in such case for the awarding of a Medal to 'each of two persons who have been jointly engaged in the same exploration in the same country, or perhaps on allied subjects in different countries, the proportion of interest always not being less to each Medal than one third of the annual interest.'

1876. Prof. John Morris.
1877. Sir James Hector.
1878. Mr. George Busk.
1879. Prof. Edmond Hébert.
1880. Sir John Evans.
1881. Sir J. William Dawson.
1882. Dr. J. Lycett.
1883. Dr. W. B. Carpenter.
1884. Dr. Joseph Leidy.
1885. Prof. H. Govier Seeley.
1886. Mr. William Pengelly.
1887. Mr. Samuel Allport.
1888. Prof. Henry A. Nicholson.
1889. Prof. W. Boyd Dawkins.
1890. Prof. Thomas Rupert Jones.
1891. Prof. T. McKenny Hughes.
1892. Mr. George H. Morton.
1893. Mr. Edwin Tulley Newton.
1894. Prof. John Milne.
1895. The Rev. John F. Blake.
1896. Dr. A. Smith Woodward.
1897. Dr. George Jennings Hinde.
1898. Prof. Wilhelm Waagen.
1899. Lt.-Gen. C. A. McMahon.
1900. Dr. John Edward Marr.
1901. Dr. Ramsay H. Traquair.
1902. { Prof. Anton Fritsch. / Mr. Richard Lydekker.
1903. Mr. Frederick W. Rudler.
1904. Prof. Alfred G. Nathorst.
1905. Dr. Hans Reusch.
1906. Prof. Frank Dawson Adams.
1907. Dr. Joseph F. Whiteaves.
1908. Mr. Richard Dixon Oldham.
1909. Prof. Percy Fry Kendall.
1910. Dr. Arthur Vaughan.
1911. { Dr. Francis Arthur Bather. / Dr. Arthur Walton Rowe.
1912. Mr. Philip Lake.
1913. Mr. S. S. Buckman.
1914. Mr. C. S. Middlemiss.

AWARDS

OF THE

BALANCE OF THE PROCEEDS OF THE 'LYELL GEOLOGICAL FUND.'

1876. Prof. John Morris.
1877. Mr. William Pengelly.
1878. Prof. Wilhelm Waagen.
1879. Prof. Henry A. Nicholson.
1879. Dr. Henry Woodward.
1880. Prof. F. A. von Quenstedt.
1881. Prof. Anton Fritsch.
1881. Mr. G. R. Vine.
1882. The Rev. Norman Glass.
1882. Prof. Charles Lapworth.
1883. Mr. P. H. Carpenter.
1883. M. Ed. Rigaux.
1884. Prof. Charles Lapworth.
1885. Mr. Alfred J. Jukes-Browne.
1886. Mr. David Mackintosh.
1887. The Rev. Osmond Fisher.
1888. Dr. Arthur H. Foord.
1888. Mr. Thomas Roberts.
1889. Prof. Louis Dollo.
1890. Mr. Charles D. Sherborn.
1891. Dr. C. I. Forsyth-Major.
1891. Mr. George W. Lamplugh.
1892. Prof. John Walter Gregory.
1892. Mr. Edwin A. Walford.
1893. Miss Catherine A. Raisin.
1893. Mr. Alfred N. Leeds.
1894. Mr. William Hill.
1895. Prof. Percy Fry Kendall.
1895. Mr. Benjamin Harrison.
1896. Dr. William F. Hume.
1896. Dr. Charles W. Andrews.
1897. Mr. W. J. Lewis Abbott.
1897. Mr. Joseph Lomas.
1898. Mr. William H. Shrubsole.
1898. Mr. Henry Woods.
1899. Mr. Frederick Chapman.
1899. Mr. John Ward.
1900. Miss Gertrude L. Elles.
1901. Dr. John William Evans.
1901. Mr. Alexander McHenry.
1902. Dr. Wheelton Hind.
1903. Mr. Sydney S. Buckman.
1903. Mr. George Edward Dibley.
1904. Dr. Charles Alfred Matley.
1904. Prof. Sidney Hugh Reynolds.
1905. Dr. E. A. Newell Arber.
1905. Dr. Walcot Gibson.
1906. Prof. W. G. Fearnsides.
1906. Mr. Richard H. Solly.
1907. Mr. T. Crosbee Cantrill.
1907. Mr. Thomas Sheppard.
1908. Prof. Thomas F. Sibly.
1908. Mr. H. J. Osborne White.
1909. Mr. H. Brantwood Maufe.
1909. Mr. Robert G. Carruthers.
1910. Dr. F. R. Cowper Reed.
1910. Dr. Robert Broom.
1911. Dr. Charles Gilbert Cullis.
1912. Dr. Arthur R. Dwerryhouse.
1912. Mr. Robert Heron Rastall.
1913. Mr. Llewellyn Treacher.
1914. The Rev. Walter Howchin.
1914. Mr. John Postlethwaite.

AWARDS OF THE BIGSBY MEDAL,

FOUNDED BY THE LATE

DR. J. J. BIGSBY, F.R.S., F.G.S.

To be awarded biennially 'as an acknowledgment of eminent services in any department of Geology, irrespective of the receiver's country; but he must not be older than 45 years at his last birthday, thus probably not too old for further work, and not too young to have done much.'

1877. Prof. Othniel Charles Marsh.
1879. Prof. Edward Drinker Cope.
1881. Prof. Charles Barrois.
1883. Dr. Henry Hicks.
1885. Prof. Alphonse Renard.
1887. Prof. Charles Lapworth.
1889. Dr. J. J. Harris Teall.
1891. Dr. George Mercer Dawson.
1893. Prof. William J. Sollas.
1895. Dr. Charles D. Walcott.
1897. Mr. Clement Reid.
1899. Prof. T. W. Edgeworth David.
1901. Mr. George W. Lamplugh.
1903. Dr. Henry M. Ami.
1905. Prof. John Walter Gregory.
1907. Dr. Arthur W. Rogers.
1909. Dr. John Smith Flett.
1911. Prof. Othenio Abel.
1913. Sir Thomas H. Holland.

AWARDS OF THE PRESTWICH MEDAL,

ESTABLISHED UNDER THE WILL OF THE LATE

SIR JOSEPH PRESTWICH, F.R.S., F.G.S.

'To apply the accumulated annual proceeds . . . at the end of every three years, in providing a Gold Medal of the value of Twenty Pounds, which, with the remainder of the proceeds, is to be awarded . . . to the person or persons, either male or female, and either resident in England or abroad, who shall have done well for the advancement of the science of Geology; or, from time to time to accumulate the annual proceeds for a period not exceeding six years, and apply the said accumulated annual proceeds to some object of special research bearing on Stratigraphical or Physical Geology, to be carried out by one single individual or by a Committee; or, failing these objects, to accumulate the annual proceeds for either three or six years, and devote such proceeds to such special purposes as may be decided.'

1903. John Lubbock, Baron Avebury.
1906. Mr. William Whitaker.
1909. Lady (John) Evans.
1912. Library extension.

AWARDS OF THE PROCEEDS OF THE BARLOW-JAMESON FUND,

ESTABLISHED UNDER THE WILL OF THE LATE

Dr. H. C. BARLOW, F.G.S.

'The perpetual interest to be applied every two or three years, as may be approved by the Council, to or for the advancement of Geological Science.'

1879. Purchase of microscope.
1881. Purchase of microscope-lamps.
1882. Baron C. von Ettingshausen.
1884. Dr. James Croll.
1884. Prof. Leo Lesquereux.
1886. Dr. H. J. Johnston-Lavis.
1888. Museum.
1890. Mr. W. Jerome Harrison.
1892. Prof. Charles Mayer-Eymar.
1893. Purchase of scientific instruments for Capt. F. E. Younghusband.
1894. Dr. Charles Davison.
1896. Mr. Joseph Wright.
1896. Mr. John Storrie.
1898. Mr. Edward Greenly.
1900. Mr. George C. Crick.
1900. Dr. Theodore T. Groom.
1902. Mr. William M. Hutchings.
1904. Mr. H. J. Ll. Beadnell.
1906. Mr. Henry C. Beasley.
1908. Contribution to the Fund for the Preservation of the 'Grey Wether' sarsen-stones on Marlborough Downs.
1911. Mr. John Frederick Norman Green.
1913. {Mr. Bernard Smith. Mr. John Brooke Scrivenor.

AWARDS OF THE PROCEEDS OF THE 'DANIEL PIDGEON FUND,'

FOUNDED BY MRS. PIDGEON, IN ACCORDANCE WITH THE WILL OF THE LATE

DANIEL PIDGEON, F.G.S.

'An annual grant derivable from the interest on the Fund, to be used at the discretion of the Council, in whatever way may in their opinion best promote Geological Original Research, their Grantees being in all cases not more than twenty-eight years of age.'

1903. Prof. E. W. Skeats.
1904. Mr. Linsdall Richardson.
1905. Mr. Thomas Vipond Barker.
1906. Miss Helen Drew.
1907. Miss Ida L. Slater.
1908. Mr. James A. Douglas.
1909. Dr. A. M. Finlayson.
1910. Mr. Robert Boyle.
1911. Mr. T. C. Nicholas.
1912. Mr. Otway H. Little.
1913. Mr. Roderick U. Sayce.
1914. Mr. P. G. H. Boswell.

Estimates for

INCOME EXPECTED.

	£	s.	d.	£	s.	d.
Compositions				175	0	0
Arrears of Admission-Fees	119	14	0			
Admission-Fees, 1914	252	0	0			
				371	14	0
Arrears of Annual Contributions	308	14	0			
Annual Contributions, 1914	1900	0	0			
Annual Contributions in advance	70	0	0			
				2278	14	0
Sale of the Quarterly Journal, including Longmans' Account				200	0	0
Sale of other Publications				5	0	0
Miscellaneous Receipts				10	0	0
Interest on Deposit-Account................				30	0	0
Dividends on £2500 India 3 per cent. Stock ..	75	0	0			
Dividends on £300 London, Brighton, & South Coast Railway 5 per cent. Consolidated Preference Stock	15	0	0			
Dividends on £2250 London & North-Western Railway 4 per cent. Preference Stock	90	0	0			
Dividends on £2800 London & South-Western Railway 4 per cent. Preference Stock	112	0	0			
Dividends on £2072 Midland Railway $2\frac{1}{2}$ per cent. Perpetual Preference Stock	51	16	0			
Dividends on £267 6*s*. 7*d*. Natal 3 per cent. Stock.	8	0	0			
				351	16	0
				£3422	4	0

[NOTE.—The accumulated interest on the Sorby and Hudleston Bequests, which will amount on December 31st, 1914, to £337 15*s*. 0*d*., is not included in the above estimate of Income expected.]

the Year 1914.

EXPENDITURE ESTIMATED.

	£	s.	d.	£	s.	d.
House-Expenditure:						
Taxes		15	0			
Fire-Insurance and other Insurance	16	0	0			
Electric Lighting and Maintenance	75	0	0			
Gas	15	0	0			
Fuel	35	0	0			
Furniture and Repairs	100	0	0			
House-Repairs and Maintenance	50	0	0			
Annual Cleaning	20	0	0			
Washing and Sundry Expenses	35	0	0			
Tea at Meetings	15	0	0			
				361	15	0
Salaries and Wages, etc.:						
Assistant-Secretary	400	0	0			
,, half Premium Life-Insurance	10	15	0			
Assistant-Librarian	155	0	0			
Assistant-Clerk	110	0	0			
W. R. Jones's Pension	100	0	0			
Junior Assistant	65	0	0			
House-Porter and Wife	94	0	0			
Housemaid	49	18	0			
Charwoman and Occasional Assistance	20	0	0			
Accountants' Fee	10	10	0			
				1015	3	0
Office-Expenditure:						
Stationery	40	0	0			
Miscellaneous Printing	60	0	0			
Postages and Sundry Expenses	75	0	0			
				175	0	0
Library (Books and Binding)				250	0	0
Library Catalogue:						
Cards	20	0	0			
Compilation	50	0	0			
				70	0	0
Publications:						
Quarterly Journal, including Commission on Sale	1000	0	0			
Postage on Journal, Addressing, etc.	100	0	0			
Record of Geological Literature	120	0	0			
Abstracts of Proceedings, including Postage	105	0	0			
List of Fellows	40	0	0			
				1365	0	0
				3236	18	0
Estimated excess of Income over Expenditure				185	6	0
				£3422	4	0

BEDFORD McNEILL, *Treasurer.*

January 29th, 1914.

[NOTE.—The cost of Redecoration of the Society's Apartments, involving a probable expenditure of about £800, is not included in the above estimate.]

RECEIPTS.

	£	s.	d.	£	s.	d.
To Balance in the hands of the Bankers at January 1st, 1913	608	16	5			
,, Balance in the hands of the Clerk at January 1st, 1913	32	5	10			
				641	2	3
,, Compositions				175	0	0
,, Admission-Fees:						
Arrears	100	16	0			
Current	302	8	0			
				403	4	0
,, Arrears of Annual Contributions	174	6	0			
,, Annual Contributions for 1913:—						
Resident Fellows	1921	10	0			
Non-Resident Fellows	1	11	6			
,, Annual Contributions in advance	73	6	0			
				2170	13	6
,, Publications:						
Sale of Quarterly Journal: *						
,, Vols. i to lxviii (less Commission £11 9*s.* 1*d.*)	173	4	6			
Vol. lxix (less Commission £3 9*s.* 9*d.*)	58	13	6			
				231	18	0
,, Other Publications (less Commission)				6	7	3
,, Miscellaneous Receipts				10	12	6
,, Interest on Deposit				37	15	10
,, Dividends (less Income-Tax):—						
£2500 India 3 per cent. Stock	70	12	8			
£300 London, Brighton, & South Coast Railway 5 per cent. Consolidated Preference Stock	14	2	6			
£2250 London & North-Western Railway 4 per cent. Preference Stock	84	15	0			
£2800 London & South-Western Railway 4 per cent. Preference Stock	105	9	4			
£2072 Midland Railway $2\frac{1}{2}$ per cent. Perpetual Preference Stock	48	15	7			
£267 6*s.* 7*d.* Natal 3 per cent. Stock	7	11	0			
				331	6	1
				£4007	19	5

* A further sum is due from Messrs. Longmans & Co. for Journal-Sales, etc.......£69 8 0

Year ended December 31st, 1913.

PAYMENTS.

	£	s.	d.	£	s.	d.
By House-Expenditure:						
Taxes		15	0			
Fire-Insurance and other Insurance	16	13	4			
Electric Lighting and Maintenance	75	7	8			
Gas	14	3	6			
Fuel	25	10	0			
Furniture and Repairs	170	14	4			
House-Repairs and Maintenance	31	11	4			
Annual Cleaning	14	19	10			
Washing and Sundry Expenses	34	17	10			
Tea at Meetings	15	7	0			
Conversazione	27	14	5			
Ventilation	3	3	0			
				430	17	3
,, Salaries and Wages:						
Assistant-Secretary	400	0	0			
,, half Premium Life-Insurance	10	15	0			
Assistant-Librarian	206	5	0			
,, Pension (W. R. Jones)	25	0	0			
Assistant-Clerk	105	0	0			
Junior Assistant	60	19	0			
House-Porter and Wife	87	16	0			
Housemaid	49	18	0			
Charwoman and Occasional Assistance	29	18	10			
Accountants' Fee	10	10	0			
				986	1	10
,, Office-Expenditure:						
Stationery	71	3	10			
Miscellaneous Printing	54	3	5			
Postages and Sundry Expenses	73	14	9			
				199	2	0
,, Library (Books and Binding, etc.)				225	4	7
,, Library-Catalogue:						
Cards	12	4	6			
Compilation	50	0	0			
				62	4	6
,, Publications:						
Quarterly Journal, Vol. lxix, Paper, Printing, and Illustrations	957	13	10			
Postage on Journal, Addressing, etc.	106	5	10			
Record of Geological Literature	16	16	0			
Abstracts, including Postage	113	13	5			
List of Fellows	38	14	3			
				1233	3	
,, Balance in the hands of the Bankers at December 31st, 1913:						
Current Account	96	12	0			
Deposit Account	750	0	0			
,, Balance in the hands of the Clerk at December 31st, 1913	24	13	11			
				871	5	11
				£4007	19	5

We have compared this Statement with the Books and Accounts presented to us, and find them to agree.

J. VINCENT ELSDEN, S. HAZZLEDINE WARREN, } *Auditors.*

BEDFORD McNEILL, *Treasurer.*

January 29th, 1914.

Statements of Trust-Funds: December 31st, 1913.

'Wollaston Donation Fund.' Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1913	32	3	8	By Cost of Medal	10	10	0
„ Dividends (less Income-Tax) on the Fund invested in £1073 Hampshire County 3 per cent. Stock	30	6	2	„ Award from the Balance of the Fund	21	13	8
				„ Balance at the Bankers' at December 31st, 1913	30	6	2
	£62	9	10		£62	9	10

'Murchison Geological Fund.' Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1913	21	3	6	By Award to the Medallist	10	10	0
„ Dividends (less Income-Tax) on the Fund invested in £1334 London & North-Western Railway 3 per cent. Debenture Stock	37	13	8	„ Award from the Balance of the Fund	29	10	4
				„ Balance at the Bankers' at December 31st, 1913	18	16	10
	£58	17	2		£58	17	2

'Lyell Geological Fund.' Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1913	53	15	9	By Award to the Medallist	40	0	0
„ Dividends (less Income-Tax) on the Fund invested in £2010 1*s.* 0*d.* Metropolitan $3\frac{1}{2}$ per cent. Stock	66	5	0	„ Award from the Balance of the Fund	30	7	0
				„ Balance at the Bankers' at December 31st, 1913	49	13	9
	£120	0	9		£120	0	9

‘Barlow-Jameson Fund.’ Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers’ at January 1st, 1913........	58	8	11	By Award from the Balance of the Fund	65	1	2
,, Dividends (less Income-Tax) on the Fund invested in £468 Great Northern Railway 3 per cent. Debenture Stock	13	4	6	,, Balance at the Bankers’ at December 31st, 1913	6	12	3
	£71	13	5		£71	13	5

‘Bigsby Fund.’ Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers’ at January 1st, 1913........	9	12	8	By Cost of Medal	12	12	0
,, Dividends (less Income-Tax) on the Fund invested in £210 Cardiff 3 per cent. Stock	5	18	8	,, Balance at the Bankers’ at December 31st, 1913	2	19	4
	£15	11	4		£15	11	4

‘Geological Relief Fund.’ Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers’ at January 1st, 1913........	39	10	2	By Balance at the Bankers’ at December 31st, 1913	43	8	10
,, Dividends (less Income-Tax) on the Fund invested in £139 3*s.* 7*d.* India 3 per cent. Stock..............	3	18	8				
	£43	8	10		£43	8	10

‘Prestwich Trust Fund.’ Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers’ at January 1st, 1913........	16	0	10	By Balance at the Bankers’ at December 31st, 1913......	35	16	2
,, Dividends (less Income-Tax) on the Fund invested in £700 India 3 per cent. Stock.....................	19	15	4				
	£35	16	2		£35	16	2

‘Daniel Pidgeon Fund.’ Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1913	16	3	7	By Award	30	11	6
„ Dividends (less Income-Tax) on the Fund invested in £1019 1*s.* 2*d.* Bristol Corporation 3 per cent. Stock	28	15	10	„ Balance at the Bankers' at December 31st, 1913	14	7	11
	£44	19	5		£44	19	5

SPECIAL FUNDS.

Hudleston Bequest.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1913	102	19	2	By Balance at the Bankers' at December 31st, 1913	135	18	4
„ Dividends (less Income-Tax) on the Fund invested in £1000 Canada $3\frac{1}{2}$ per cent. Stock	32	19	2				
	£135	18	4		£135	18	4

Sorby Bequest.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1913	102	19	2	By Balance at the Bankers' at December 31st, 1913	135	18	4
„ Dividends (less Income-Tax) on the Fund invested in £1000 Canada $3\frac{1}{2}$ per cent. Stock	32	19	2				
	£135	18	4		£135	18	4

We have compared this Statement with the Books and Accounts presented to us, and find them to agree.

BEDFORD McNEILL, *Treasurer.*
January 29th, 1914.

J. VINCENT ELSDEN,
S. HAZZLEDINE WARREN, } *Auditors.*

Statement relating to the Society's Property:

December 31st, 1913.

	£ s. d.	£ s. d.
Balance in the Bankers' hands, December 31st, 1913:		
On Current Account	96 12 0	
On Deposit Account	750 0 0	
Balance in the Clerk's hands, December 31st, 1913	24 13 11	
		871 5 11
Due from Messrs. Longmans & Co., on account of the Quarterly Journal, Vol. LXIX, etc.	69 8 0	
Arrears of Admission-Fees	119 14 0	
Arrears of Annual Contributions	308 14 0	
		497 16 0
		£1369 1 11
Funded Property, at cost price:—		
£2500 India 3 per cent. Stock	2623 19 0	
£300 London, Brighton, & South Coast Railway 5 per cent. Consolidated Preference Stock	502 15 3	
£2250 London & North-Western Railway 4 per cent. Preference Stock	2898 10 6	
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£267 6*s.* 7*d.* Natal 3 per cent. Stock	250 0 0	
£2000 Canada 3½ per cent. Stock	1982 11 0	
		13,716 2 9

[NOTE.—*The above amount does not include the value of the Library, Furniture, and Stock of unsold Publications. The value of the Funded Property of the Society, at the prices ruling at the close of business on December 31st, 1913, amounted to £9,303 14s. 6d.*]

BEDFORD McNEILL, *Treasurer.*

January 29th, 1914.

Award of the Wollaston Medal.

In presenting the Wollaston Medal to Dr. John Edward Marr, F.R.S., the President addressed him as follows:—

Dr. Marr,—

I am pleased that it has fallen to my lot to address, on such an occasion as this, one with whom I have so long enjoyed an intimate friendship, and by whose work I have profited so greatly.

At the conclusion of a distinguished University career you commenced, in 1878, a series of investigations, through which your name will always be associated with the Lower Palæozoic rocks. Concentrating your attention first on the zoning of the strata between the Coniston Limestone and the Coniston Grits in the Lake District, you continued the work of Hughes, Aveline, and Salter, established a classification, and discussed the division between the Silurian and those Cambrian subdivisions of Sedgwick which are now known as Ordovician. In 1880 you carried your researches into North Wales, and instituted a comparison of the sequence as there developed with that of the Lake District. During the same year you laid before this Society the results of your visit to Bohemia, where you had been commissioned by the University of Cambridge to investigate the 'Cambrian' and Silurian sequences, with special reference to the boundary between them. In carrying this work to a successful issue, you were not only able to institute a comparison of the Bohemian and British developments, but incidentally to show that there existed serious objections to the acceptance of Barrande's 'colonies,' both on palæontological and on stratigraphical grounds. Extending your investigations to Scandinavia, you proved that Sedgwick's classification was applicable in that country also, and that the principal stratigraphical and physical break occurred at the base of the equivalents of our May Hill Beds.

Your ripe experience of the Lower Palæozoic rocks was then turned to account in South Wales, where, in collaboration with the late T. Roberts, you undertook the task of subdividing the groups which had been outlined by the early surveyors. Your success in carrying out this programme may be judged when I say that during the recent re-examination of the district by the Geological Survey, all the subdivisions made by you and your

colleague in 1885 were adopted, and will be utilized in the forthcoming maps and memoirs.

Returning later to the scene of your earliest labours, with the late H. A. Nicholson as your colleague, you completed further palæontological zoning in the Stockdale Shales, and proved by precise field-work that an appearance of unconformity between the lowest zone and the Ashgill Shales was deceptive and due to strike-faulting.

In 1891, with Dr. A. Harker, you made a detailed study of the effects produced by the intrusion of the Shap Granite upon the surrounding rocks. Your familiarity with the Lake District strata, combined with the petrographical skill of your colleague, enabled you jointly to produce a classic account of the phenomena of contact-metamorphism, as exhibited in calcareous and siliceous sediments, and in igneous rocks.

Of late years physiographical problems have engaged your attention, and, as a result of your observations on mountain-lakes, it may be expected that a wiser caution will be exercised than heretofore in identifying rock-basins as such, and in postulating glacial erosion for tarns.

But it is not only this long record of original research, of necessity incompletely outlined, which the Council have had in mind in making this Award. They remember that since 1880 you have been continuously engaged at your old University in assisting the Woodwardian Professor to create the foremost school of geology in Britain. The influence of your teaching in the lecture-room, in the field, and as conveyed by your text-books, has extended farther than perhaps you yourself realize. A happy combination of the power to make original research with a facility for imparting your knowledge, has enabled you to exercise a profound influence on the growth of our science.

It is, therefore, with great satisfaction that I hand to you, on behalf of the Council, the highest honour which it is in their power to bestow—the Wollaston Medal.

Dr. Marr, in reply, said:—

Mr. President,—

I feel that the award of this Medal is due to a combination of a number of favourable circumstances.

I have been fortunate in having worked and published papers in

conjunction with many geologists, including T. Roberts, Nicholson, Harker, Garwood, and Fearnsides. Two of them have, alas! passed away, and one of the great griefs of my life was the loss of that ardent geologist and genial companion, Alleyne Nicholson.

My long association with this Society as Officer and Member of Council has brought me into contact for many years with men from whom I could learn the results of the recent discoveries in our science.

I regard this Award as made, not only to myself, but to the Cambridge School of Geology; and in speaking of this school I would first bear tribute to the advantage of the teaching which I received in my undergraduate days from Prof. Hughes and Prof. Bonney. During the 'seventies a number of brilliant geologists emerged from that school, of whom you, Sir, were one. I cannot help acknowledging also the benefits of the teaching in the field, which I received from an Oxford man whom I have the honour of counting as a friend of over forty years' standing—Mr. Tiddeman.

I have, as you observed, for many years, been myself a teacher in the Cambridge School, and here again have benefited from the ardour and enthusiasm of my pupils. Their cordial congratulations to me on receiving this Award show that they, as well as I, appreciate the honour.

Before passing from the subject of Cambridge, I must refer, Sir, to our old College. It is, no doubt, a satisfaction to you as to me to find the names of five members of St. John's enrolled in the list of the Wollaston Medallists within the last twenty-five years.

I thank the Council most sincerely for the bestowal of this their highest award. There is, however, an honour which I should rank still higher, and that is the cordial approval which I feel that the Council and general body of the Fellows would accord to one who did his utmost to serve the interests of the Science and of the Geological Society to the end of his life. The desire to gain this approval will surely stimulate me to work in the future.

Award of the Murchison Medal.

The President then presented the Murchison Medal to Mr. William Augustus Edmond Ussher, F.G.S., addressing him in the following words:—

Mr. USSHER,—

For more than forty years, as a member of the staff of the Geological Survey, you devoted yourself whole-heartedly to the work entrusted to you. Though at one time or another you were engaged in various parts of England, the South-Western Counties are those with which your name is most closely associated. Indeed, among the many distinguished men who have laboured in Cornwall, Devon, and Somerset, you have done more than most to unravel the tangle of Palæozoic rocks, and to classify the Newer Red rocks there exposed.

So long ago as 1875 you communicated your first paper on the Trias to this Society, and two years later you followed this up by a comparison of the Triassic development of the South-West of England with those of the Midlands and of Normandy.

At this time also you began to publish the results of those researches on the Palæozoic sequence which were destined to fill so large a part of your official career. Partly in association with the late A. Champernowne, and with help derived from the writings of De la Beche and other early workers in the same field, you proceeded with what seemed the almost hopeless task of interpreting the structure of the country and defining the limits of the Carboniferous rocks, and of the Upper, Middle, and Lower Devonian groups. It is not possible for me, on this occasion, to trace the steps by which you reached your final conclusions. I can only refer to your published accounts in the Journal of this Society, in the Memoirs of the Geological Survey, and in the Transactions of the Devonshire Association, and assure you that the exceptional difficulty of the task which fell to you, involving as it did a bewildering complexity of structure, difficult palæontology, and for a time at least an inadequate topographical basis for your work, is recognized by all geologists. The Council desire to take this opportunity of testifying their appreciation of your efforts, and on their behalf I beg to hand you the Murchison Medal.

Mr. USSHER replied in the following words:—

Mr. PRESIDENT,—

I sincerely thank you, the Council, and the Fellows of this Society for the honour thus conferred upon me, and for the unanimity with which it has been bestowed. The work to which,

Sir, you so flatteringly refer was done so long ago that this recognition is doubly grateful, as a convincing proof that my researches have not been forgotten.

My work among the New Red rocks of the South-Western Counties, begun in 1870 and completed in 1880, was inspected by my old chief, Sir Andrew Ramsay, who characterized it as 'first-class work,' a commendation most encouraging at the time and still a highly-prized remembrance. This work has not all been officially published, even now.

The discovery of the structure and succession of the Devonian rocks would have been effected by a dear friend of mine, the late A. Champernowne, but for his untimely death in 1886. In 1888–89 I was employed in endeavouring to reconcile the different versions of Champernowne's work, with a view to publication; and I made an earnest attempt to solve the doubts which Champernowne entertained as to the relative positions of certain members of his sequence. The solution of these problems led to the establishment of the true Devonian succession in South Devon, and to the correlation of the subdivisions with those of the Continent. In this work I have been greatly assisted by Continental geologists, among whom my old friend Prof. Gosselet (a former recipient of the Murchison Medal) figures prominently. The tentative application of this succession to Cornwall in 1891 was proved to be substantially correct by the subsequent work of the Geological Survey.

In conclusion, Sir, allow me to renew the expression of my thanks for the honour conferred upon me.

Award of the Lyell Medal.

In handing the Lyell Medal, awarded to Charles Stewart Middlemiss, B.A., to Sir Thomas H. Holland, K.C.I.E., for transmission to the recipient, the President addressed him as follows:—

Sir Thomas Holland,—

During a service of more than thirty years on the Geological Survey of India, Mr. Middlemiss has done much to advance our knowledge of the geology of that country.

He was one of the first to apply modern microscopical methods to Indian problems, and by their use in dealing with palagonite-bearing traps and the phenomena of contact-metamorphism arising from the intrusion of the Himalayan central granite, was able to make important contributions to the science of Petrography. We are indebted also to him for a great extension in our knowledge of the Archæan complex in the southern and south-eastern parts of the Indian peninsula.

In his studies on tectonic geology in the Sub-Himalaya of Kumaon, the frontier district of Hazara, and the Salt Range of the Punjâb, he has displayed a marked originality, and his more recent work in Kashmir has done much to elucidate the pre-Tertiary geography of Gondwanaland. His investigations of the Bengal earthquake of 1885, and his elaborate analysis of the phenomena accompanying the disastrous Kangra shock in 1905, form valuable additions to the seismological record. No less has applied geology benefited by his investigations on the stability of slopes in mountainous regions.

The papers in which Mr. Middlemiss has presented his results enrich the publications of the Geological Survey of India, not only by their scientific value, but by the literary charm of his pen and by the happy facility of his pencil.

In recognition of this great record of work, the result of single-hearted devotion to his duties, I ask you to forward to Mr. Middlemiss, on behalf of the Council, the Lyell Medal.

Sir Thomas Holland, in reply, said:—

Mr. President,—

It gives me special satisfaction in this way to represent my Service in acknowledging the honour bestowed on a colleague, who, by his unselfish devotion to work and his gentle disposition, has so conspicuously earned the affectionate respect of every officer with whom he has worked.

You have referred, Sir, both judicially and judiciously, to the excellent quality of Mr. Middlemiss's long record of published results; but only those of us who have been his colleagues in India can form a sufficient appreciation of his perfect freedom from personal ambition and his disinterested devotion to the science of Geology.

By reason of a combination of chances such as often affects a

service which is partly official and partly scientific, I have had the peculiar opportunity of discovering the fine personal qualities of Mr. Middlemiss from two distinct points of view; for I have had the pleasurable privilege of working directly under him in the field, and have had the honour also of being his official chief. Having thus seen him from all sides, I can confidently assert that Mr. Middlemiss's record of good work has no seamy side. This Award will be keenly appreciated by all past and present members of the Indian Geological Survey; a referendum made to that critical community would have found Mr. Middlemiss returned unopposed.

The choice of the Lyell Medal is especially appropriate, as the chance possession in his youth of a copy of the 'Student's Elements' was, as we in India know, the work which turned Mr. Middlemiss to the study of Geology.

In writing from India to express his appreciation of the Award now made by the Council, Mr. Middlemiss states with obvious sincerity that

> 'Much of the pleasure that I have derived from my geological work in this country has been enhanced by the friendly and helpful relations that have always existed between myself and my colleagues, who, I know, rejoice with me in the Award.'

Award from the Wollaston Donation Fund.

The President then presented the Balance of the Proceeds of the Wollaston Donation Fund to Mr. Richard Bullen Newton, F.G.S., addressing him in the following words:—

Mr. Newton,—

After some years in the Palæontological Department of the Geological Survey, you were transferred, in 1880, to the Geological Department of the British Museum (Natural History). During this long service in two public departments, not only has your work been distinguished by care and thoroughness, but you have utilized your opportunities for making yourself well acquainted with the Gasteropoda and Lamellibranchiata, more especially of the younger geological formations. The contributions which you have thus been able to make to the palæontology of parts of Africa and Asia, in addition to your work in the British Isles, have enriched the pages of our Journal for many years. On behalf of the Council, I beg to hand to you the Balance of the Proceeds of the Wollaston Fund.

Award from the Murchison Geological Fund.

In presenting the Balance of the Proceeds of the Murchison Geological Fund to Mr. Frederick Nairn Haward, the President addressed him as follows:—

Mr. Haward,—

At a time when enthusiasm in the pursuit of proofs of human workmanship on flints has threatened to outrun discretion, you have engaged in a study of the various forms of fracture which can result from natural causes, in order to demonstrate that much of the chipping attributed by some observers to Man may have been due to natural agencies. Your minute and unbiassed investigations cannot fail to exercise a useful influence on the treatment of this speculative subject. In handing to you the Murchison Geological Fund, awarded to you by the Council of this Society, I express the hope that you will regard it as a mark of appreciation of what you have already done, and as an encouragement to continue your researches.

Awards from the Lyell Geological Fund.

The President then handed a Moiety of the Proceeds of the Lyell Geological Fund, awarded to the Rev. Walter Howchin, F.G.S., to Prof. W. W. Watts, F.R.S., for transmission to the recipient, addressing him as follows:—

Professor Watts,—

Before leaving this country, upwards of twenty years ago, Mr. Howchin had already done useful work on the Carboniferous foraminifera. On his arrival in Australia, he continued his studies on these organisms in the Tertiary, Cretaceous, and Permo-Carboniferous rocks. It was during the prosecution of his researches among the Permo-Carboniferous glacial deposits that he came upon widespread 'tillites' at a horizon lower than that of the *Olenellus* and *Salterella* Beds of the Lower Cambrian. The glacial phenomena presented by these rocks were first described in detail in a convincing paper laid by him before this Society in 1908, although a preliminary note on their existence had been read before the Royal Society

of South Australia in 1901. In addition to his researches upon these extraordinarily interesting episodes in Palæozoic times, Mr. Howchin has done much to elucidate the complicated structure of Mount Lofty, and the general physiography of South Australia. In making the Award, which I now beg you to forward to him, the Council desire to express their sense of the great importance to Geological Science of the work that he has done in far-distant Australia.

In presenting the other Moiety of the Proceeds of the Lyell Geological Fund to Mr. JOHN POSTLETHWAITE, F.G.S., the PRESIDENT addressed him in the following words:—

Mr. POSTLETHWAITE,—

For more than forty years your name has been associated with the geology of the Lake District, for it was in 1874 that you read a paper at Keswick on the Mines & Minerals, which was destined to develop into the useful and beautifully-illustrated book, re-issued in third edition only last year. Though minerals and ores have claimed much of your attention, the igneous rocks with which they are so often associated have been studied in the field and described by you in the pages of our Quarterly Journal. To you also is due the credit of having helped to clear away the obscurity attaching to the age of the Skiddaw Slates by your indefatigable and successful search for fossils.

The award, which it is my privilege to hand to you, has been allotted to you by the Council in testimony of their appreciation of your work in the classic ground of the English Lake District.

THE ANNIVERSARY ADDRESS OF THE PRESIDENT,

AUBREY STRAHAN, Sc.D., LL.D., F.R.S.

THE twelve months which have elapsed since our last Anniversary Meeting have not passed without the loss of many eminent geologists, both at home and abroad. No fewer than six of the illustrious foreigners whom we were proud to include in our lists have been removed by death: Rosenbusch, Fritsch, Credner, Tschernyschew, and Baltzer, are gone from among our Foreign Members, and in Cocchi we have lost a Foreign Correspondent.

With regard to the following obituaries I am indebted to Prof. Gregory, Prof. Judd, Dr. Henry Woodward, Dr. Harker, and Dr. A. S. Woodward, for each supplying an appreciation of the life and work of an old friend. To the kindness of Dr. Karpinsky I owe the information on which the notice of Tschernyschew is based.

The death of Geheimrath Professor HARRY ROSENBUSCH removes one who had long been an acknowledged master in an important branch of modern geology. His great-grandfather and grandfather had been miners in the Harz, but his father, Georg Wilhelm Heinrich Rosenbusch, removed to Einbeck in Hanover, where he became master of an orphan-asylum. He was married to Luise Frederike Henriette, by birth Püschel. Their eldest son was born at Einbeck on June 24, 1836, and was named Karl Harry Ferdinand. The English Christian name, by which he preferred to be known, was at that time not uncommon in Hanover, a memory of the long political connexion between the two countries. A second son, August Enrik Eduard, became afterwards an Inspector of Telegraphs in the British service; and there was a third boy, who lived only ten months.

The father died in 1843, leaving his widow in very straitened circumstances. She contrived, however, by hard work, to send her two boys to the local grammar-school, where they made good progress, and added to the scanty resources of the family by helping their younger schoolfellows in their lessons. The early predilection of young Rosenbusch was for languages, and he became indeed an accomplished linguist, speaking French, Italian, Spanish, Portuguese, and English. In due course he entered the University of Göttingen as a student of philology; but his means did not enable

him to complete his course there, and he was glad to accept an offer from a rich South American, who wanted a tutor for his two sons. In this capacity Rosenbusch passed about five years of his life at Bahia; in Brazil.

This part of his life is only imperfectly known, and in particular we are not informed how he was led to exchange literary for scientific interests. When he returned to Germany, it was to study science at Freiburg and Heidelberg, and he received his doctorate from the former University in 1868, at the late age of thirty-two. At that time the application of the microscope to the study of rocks was in its infancy. Zirkel, inspired by Sorby, had led the way, and had already proved some of the capabilities of this line of attack. Rosenbusch was attracted to the new study. His inaugural dissertation was on the nephelinite of Katzenbuckel, near Heidelberg; and in the enthusiastic preface by which it is introduced we can read the language of a man who is conscious of having found his life-work.

The pioneers in this line encountered difficulties which, thanks to their labours, their successors can scarcely realize. The minerals in a rock-slice, presenting quite new appearances, had to be recognized by new tests. The application of the polariscope to this end had been indeed one of Sorby's own contributions, but in practice it was employed at first only in a general way. Mineralogists had, however, examined the optical properties of numerous minerals in sections cut in determinate directions. Rosenbusch collected these data, supplemented them by observations of his own, and showed how they could be systematically applied to the identification of crystals cut in random directions in a rock-slice. In this way he laid the foundation of microscopical petrography as an exact science. His results were published in 1873 in the 'Mikroskopische Physiographie der petrographisch wichtigen Mineralien,' which was followed four years later by the companion volume on igneous rocks.

In 1873 also he was appointed Professor Extraordinarius at Strassburg, and for some years he was attached to the Geological Survey of Alsace-Lorraine. The chief fruit of his work here was the well-known memoir on the Steigerschiefer and their metamorphism by the granites of the Vosges. In 1878 he was chosen for the chair of Mineralogy and Petrography in the University of Heidelberg, and began that career as a teacher which he pursued so long and so brilliantly. His laboratory became the resort of

students from many countries, who were attracted no less by his personal qualities than by his genius and encyclopædic knowledge. Many of the leading petrographers of the present day have been eager disciples of Rosenbusch, as may be seen in the 'Festschrift' by which his old students celebrated his seventieth birthday.

His specific contributions to petrography and the chemistry of rocks were numerous and valuable, and he was also from 1888 to 1907 Director of the Geological Survey of Baden; but his memory will be associated chiefly with his teaching at Heidelberg and with his monumental work, the 'Mikroskopische Physiographie.' This has passed through four editions; and it is remarkable, alike for the comprehensive knowledge of the subject which it testifies, and for the critical acumen shown in handling so multifarious a body of material.

He was the recipient of numerous honours, at home and abroad. He was elected a Foreign Correspondent of this Society in 1886, and a Foreign Member in 1890. In 1903 the Wollaston Medal was awarded to him. Excepting a memorable excursion to Norway in 1888, his geological travels belong mostly to the years before 1878. During his Professorship, and after his retirement, he was to be found usually at Heidelberg, where he lived in a villa named after his native town. He had married in 1869 Fraülein Auguste Müller, also of Einbeck. His wife survives him, but their only son died in childhood, a loss which was deeply felt. After enjoying good health to an advanced age, Geheimrath Rosenbusch died, after a short but painful illness, on January 20th, 1914, in his 78th year.[1]

[A. H.]

Prof. Anton Fritsch, who became a Foreign Correspondent of the Society in 1888 and a Foreign Member in 1897, was born at Prague in 1832, and spent all his life in that city. He was appointed assistant in the Zoological Department of the Royal Bohemian Museum in 1852, and eventually attained the directorship of the Natural History Departments of the Museum, which he still held at the time of his death. For many years he was also Professor of Zoology in the Royal Bohemian University, and the responsible head of the Natural History and Geological Survey of the Kingdom of Bohemia. His early researches were almost entirely zoological, but association with Barrande appears to have

[1] [For most of the personal details concerning Prof. Rosenbusch I am indebted to his friend and successor, Prof. E. A. Wülfing.—*A. H.*]

soon directed his attention to palæontology, and in 1861 he published his first two notes on fossils from the Silurian formation. During subsequent years he communicated numerous brief notes on Bohemian fossils to the Royal Bohemian Society of Sciences, until in 1872 he published his first separate work (in co-operation with Dr. V. Schlönbach) on the Cephalopoda of the Bohemian Cretaceous Formation. The Cretaceous fossils continued to interest him, and in 1878 he published another separate volume on the Reptiles and Fishes, which was followed by various notes on these and other fossils in his stratigraphical memoirs issued by the Bohemian Survey. Prof. Fritsch's best-known work, however, is his 'Fauna der Gaskohle & der Kalksteine der Perm-Formation Böhmens,' a series of four fine volumes published in parts between 1879 and 1901. It is especially noteworthy for the profusely-illustrated descriptions of the Permian Labyrinthodonts, based on material so unpromising that previous authors had neglected it. Prof. Fritsch prepared the fossils with his own hands, removing the decaying pyritized bones and then obtaining an exact impression of the resulting cavities in the shale by an electrotype process. He was thus able to add much to our knowledge of the early lung-breathers, and the Geological Society expressed its appreciation of these researches by awarding to Prof. Fritsch a moiety of the Lyell Fund in 1881 and a Lyell Medal in 1902. He visited England four times, in 1861, 1863, 1887, and 1899, and travelled extensively in the interests of the Royal Bohemian Museum, the new building of which for natural history he had the gratification of seeing completed under his direction in 1891. He died at Prague on November 15th, 1913. [A. S. W.]

Theodosius Nikolaievich Tschernyschew (Černyšev) was born at Kiev in 1856, and was educated in the local classical college, and in the Naval School and Mining Institute at St. Petersburg. He became a member of the staff of the Geological Survey of Russia at its institution in 1882, and was appointed Director in 1903. In 1899 he was elected a member of the Imperial Academy of Sciences at St. Petersburg, and became Director of the Geological Museum in 1903. For nearly 22 years he was Secretary of the Imperial Mineralogical Society, and for 3 years he performed the duties of Professor and Director of the Mining Institute.

Notwithstanding these varied duties at home, Tschernyschew found time to carry his field-work into remote regions. The first

papers of which I have record were published in 1883. They contained an account of a meteorite which fell at Sarátov in 1882, and the first instalment of his work on the Silurian and Devonian strata in the Southern Urals.

In 1885 he was engaged in Central Russia on the Permian rocks of the province of Kostroma, but five years later he was connected with work in progress in the far north. In the region of the Timan Mountains, he noted the occurrence of crystalline rocks, and of schists closely allied to Silurian and Devonian strata. Here also he identified Upper Devonian with abundant small crustacea, Carboniferous, Callovian, Kimeridgian, Neocomian, and post-Pliocene deposits. In 1892 his attention was drawn at Kanine, one of the northernmost points of Siberia, to the evidences of a passage of crystalline schists into unaltered sediments through the action of chemical and mechanical metamorphism.

At this time he was studying also the glacial phenomena exhibited in Northern Russia, and especially those of the Ural Mountains. He concluded that the Polar Sea must have been united with the Baltic on the one side and the Caspian on the other, and had obliterated such morainic deposits as had been left by the ice-sheet. No traces of Palæolithic Man, contemporaneous with the Mammoth, were discoverable.

Southern and Central Russia formed the scene of his labours in 1893. In the Altai Mountains, on the borders of the Chinese Empire, he studied a Devonian fauna, and compared it with that of the Coblenzian type of the Rhine district. The Carboniferous rocks of the Donetz were shown by him to present a sequence similar to that of other parts of the Empire, and to have been deposited in a gulf of the great Russian Carboniferous basin.

In the Ural Mountains his work was of far-reaching importance, especially as regards the Silurian, Devonian, Carboniferous, and Permian faunas. In the Eastern Ural he described or enumerated a large number of fossils from the Devonian, and recognized the existence of two assemblages which he compared respectively with the Hercynian and Coblenzian faunas. His work on the Devonian rocks is published in detail in the 'Memoirs of the Russian Geological Survey' vols. i & iii.

In 1896, reporting on an expedition to Novaya Zemlya, he described briefly a southern mountain-range composed of upturned Devonian rocks and a central plain underlain by the Artinskian Sandstone of Lower Permian age. In 1907 he published an

account of the discovery of Upper Trias in the Caucasus. He was a member of the Russo-Swedish Expedition to Spitsbergen.

Tschernyschew's work lay, for the most part, in remote and little-known parts of the world. While following in the footsteps of Murchison, De Verneuil, Keyserling, and Karpinsky, he may himself be regarded as one of the pioneers of European geology, for he traced the geological formations with which we are familiar, and identified their characteristic fossils, in the uttermost parts of the Continent, beyond the regions where they were known, or might even have been expected to occur.

His was a popular name abroad, as well as in Russia. To his energy the Seventh International Geological Congress, held at St. Petersburg in 1897, owed much of its success, and as a frequent attendant at subsequent Congresses it fell to him to take an important part in many international scientific enterprises, such as the Geological Map of Europe, the Geological Map of the World, and others.

Many scientific societies or institutions claimed Tschernyschew as either honorary or ordinary member, and the Universities of Marburg, Geneva, Christiania, Greifswald, and Toronto, conferred upon him the degree of Doctor *honoris causâ*. He was elected a Foreign Member of our Society in 1909.

Tschernyschew was a welcome participator in the Twelfth International Congress, held at Toronto last August, and took an active part in the proceedings. No sign of failing health was then apparent, and his sudden death on January 15th, 1914, came as a shock to a wide circle of friends.

The death of Credner, who was elected a Foreign Member of this Society in 1898, has speedily followed upon that of Zirkel, his fellow-professor in the University of Leipzig—their teaching associateship having commenced as far back as the year 1870.

Geheimrath Hermann Credner was the eldest of four sons of Heinrich Credner, a well-known geologist and mineralogist, who was a mining official, first in the Kingdom of Hanover, and after 1870 under the Imperial German Government. Born in 1841 at Gotha, the younger Credner was educated at the Clausthal Mining School and the Universities of Breslau and Göttingen. His earliest studies were devoted to the rocks and fossils of Gault and Neocomian age in Hanover, and the writer of this notice recalls with gratitude the friendly assistance received by him, when on a geological tour, from his German fellow-student. In 1864, however,

Credner sought a wider sphere of labour by journeying to the United States, where he spent four years, acting as a mining expert in the search for gold, but taking every opportunity for widening his knowledge of geological science. At a time when road and rail had not yet opened up the country, he traversed the whole of the States between New York and Nevada, and from Michigan to Georgia, recording his observation in a number of valuable memoirs.

Returning to his native country after his long wanderjahr, he, in 1869, became a privat-docent under Naumann in the University of Leipzig; and in the following year, when Zirkel succeeded Naumann, he was appointed Professor Extraordinarius, to teach Historical Geology and Palæontology, becoming a full Professor in 1877.

One of Credner's first labours in his new position was to prepare his well-known and admirable text-book 'Elemente der Geologie,' which, during the lifetime of its author, passed through no less than eleven editions, each of which was revised, expanded, and brought up to date by the indefatigable Professor.

Credner was now, however, to enter upon a still wider field of labour. Saxony, the birthplace of Mining Geology, had already been twice mapped geologically; first, at the close of the eighteenth century under the auspices of the illustrious Werner himself, and secondly, between 1835 and 1845, by Naumann and Von Cotta. But in 1872, the Government having decided on the preparation of a new and more detailed map, Credner was chosen to organize and direct the staff of surveyors. Between the date of his appointment and the year 1899, Credner with his able assistants issued no less than 127 sheets of the map as well as the accompanying memoirs, and in 1908 he was able to issue his beautiful geological map of the whole country on a reduced scale.

In connexion with his work upon the Geological Survey, Credner wrote notable papers in scientific journals dealing with many important questions, such as his views on the Saxon granulite formation, the Oligocene and other Tertiary strata, the phosphatic deposits, and the glacial phenomena of the country. But these labours did not exhaust his energies, for between the years 1881 and 1894 he issued, in ten parts, his important palæontological memoir on the Stegocephali and Saurians of the Rotliegende of the Plauenschen Grund near Dresden; while between 1897 and 1903 he devoted much attention to the study of earthquakes,

writing a number of papers which dealt with local occurrences and the construction of seismological apparatus. No fewer than 130 scientific papers stand to his record, in addition to his official publications.

Upon his attaining the age of 70, Credner's fellow-geologists showed their high appreciation of his great services to our science by raising the sum of £1000, which they placed in the hands of the Council of the German Geological Society, to be called the Hermann-Credner Fund and to be applied in assisting young geologists in their researches. Geologists in other countries who knew and corresponded with Credner can testify to his geniality and readiness to give help on all occasions. He died, after a long and painful illness, on July 21st, 1913, at the age of 72. [J. W. J.]

Richard Armin Baltzer was born on January 16th, 1842, and was the son of the pastor of the town of Zwickau in Saxony. The religious struggle of that period shortly afterwards drove his father from Germany, and Baltzer spent his boyhood in Belgium and Switzerland. In 1860 he entered the University at Zurich, where his family settled in 1865. Baltzer studied geology there under Escher von der Linth. In 1864 he removed to Bonn, where he seems to have been mainly engaged in zoological work. His love of mountaineering led him to return to Switzerland, and his first appointment was as assistant in the High School at Zurich to the chemist Wislicenus. In 1868 he became Professor of Geology, Mineralogy, & Chemistry at the Cantonal Technical School in Zurich and also privat-docent at the University and Polytechnic. In 1884 he succeeded Bachmann as Professor of Geology & Mineralogy in the University of Berne, and a year later he founded the Mineralogical & Geological Institute of Berne. He retained his Professorship and the Directorship until his death.

Baltzer was clearly a successful teacher, and he is described by his colleague Prof. Hugi as a man of exceptionally high character, who strove with all his power to live up to his own conception of his duties. Baltzer was wont to declare that

> 'the educational efficiency of a professor depends less on his scientific fame than on his personality, enthusiastic inspiration, and teaching talent. The man and his knowledge must be one, for only thus are they a living influence.'

He was a man of great physical strength and an able mountaineer The last years of his life were clouded by great suffering;

periodic prostrating headaches preceded a stroke of paralysis, and he died at Hilterfingen, on the Lake of Thun, on November 4th, 1913, after a painful and lingering illness.

Baltzer's work may be divided into three groups—his foundation of the Geological & Mineralogical Institute at Berne, to which for twenty-nine years he devoted most of his thought and energy, his researches on Alpine Tectonics, and his contributions to Glacial Geology. His first paper was on the geology of the Adamello Group, and was contributed to the Jahrbuch of the Swiss Alpine Club in 1870. This was followed by a work on the Glärnisch in 1873. In 1874 and 1875 he published some studies on recent eruptive rocks, collected during a visit to Sicily and the Lipari Islands. His most important Alpine monograph was on the 'Mechanical Contact of Gneiss & Limestone in the Bernese Oberland,' published in 1880, in which he showed that the superposition of the gneiss was due to its having been overthrust. The position of the gneiss had been attributed to its eruptive origin; but Baltzer proved that the contact between the two series showed only dynamic, and not igneous contact-phenomena. His extension of this work westwards across the Lauterbrunnen Valley, south of the Lake of Thun, was published in 1907, in his last great Alpine monograph. In 1901 Baltzer also applied the explanation of overthrusting to the geology of Lago d' Iseo, where in the Camonica valley some ancient quartz-phyllites and Permian and Triassic rocks have been pushed southwards on to rocks belonging to the two later systems.

In 1888, in his monograph on the middle part of the Aar massif, he described the much disputed 'gneisses' of the Haslithal with their Carboniferous plant-stems; and he then adopted a 'younger gneiss series,' but, probably in consequence of the work of Prof. Bonney, he subsequently recognized the uncertainty of this view, and in his 1901 monograph he left the age of the gneisses and phyllites doubtful, assigning them either to the Archæan or to the Palæozoic.

Baltzer also devoted much attention to Glacial Geology, and was much interested in the origin of lake-basins and the rate of glacier-erosion. He described the Lower Grindelwald Glacier in 1898, and drilled a series of boreholes, in order that future geologists might test the actual rate of ice-erosion. In his various discussions of this problem he showed his usual moderation of view, by proclaiming that he accepted neither the estimate that glacial erosion is enormous nor that it is insignificant. In his monograph on Lago d' Iseo he

described a remarkable series of nine terraces which have been cut in the moraines, and showed that the oldest and highest have been the most inclined, indicating the tilting of the district in post-Glacial times. He rejected the view of the glacial origin of this lake-basin, which he explained as a greatly altered river-valley. According to him dislocation was the chief factor in the origin of this basin, and he placed ice-erosion among the secondary factors.

From the evidence of the Lago d' Iseo district he accepted the view that there have been two Alpine interglacial periods. Probably his most important glacial monograph is that upon the deposits of the Diluvial Aar Glacier, accompanied by a detailed map of the Glacial deposits around Berne. He there again combated the view that glaciers are agents of great erosion, although he admitted that they might conceivably act as such if flowing at high velocity, in great mass and for a prolonged time. In his later years Baltzer wrote a considerable series of short papers on glacial deposits, including those of Switzerland, Northern Italy, and Rügen, on the origin of Alpine lake-basins, and on the tectonic structure of the Alps. In 1906 he issued his very useful guide to the geology of the Bernese Oberland, the biggest volume in the 'Sammlung Geologischer Führer.' The last of his list of about 50 papers was a short note in 1909 on his Lago d' Iseo monograph.

The general impression left by a review of Baltzer's work is that of an accurate, cautious investigator, whose conclusions showed keen insight, whose views were fair and moderate, and who has had a deep influence on Alpine Geology.

He was elected a Foreign Correspondent of this Society in 1907, and a Foreign Member in 1911. [J. W. G.]

Igino Cocchi was born at Terrarossa in the Val di Magra (Province of Massa) in 1828. He at first devoted himself to literary studies, especially Latin literature, afterwards to chemistry, anatomy, and botany, and finally to mineralogy and geology, especially palæontology and stratigraphy.

Having graduated at the University of Pisa, he completed his studies abroad, more especially in Paris and London. Later on, he gave to the city of Florence his specimens, which formed the nucleus of an important palæontological collection.

After returning to Pisa, he was for a time assistant to Savi and Meneghini; he collaborated with Count A. Spada and others in the reorganization of their collections, and finally was appointed

Professor of Geology & Mineralogy at the Reale Istituto di Studi Superiori in Florence.

He founded the Alpine Club of Florence, and in 1867, under successive Ministers of Agriculture (Cordova and afterwards Broglio), established the Reale Comitato Geologico.[1]

He was not a prolific writer. Only a dozen papers stand to his credit in the Royal Society's Catalogue, and some twenty or so separate memoirs.

He was elected a Foreign Correspondent of the Geological Society of London in 1874, and died at Florence on August 18th, 1913. [H. W.]

John Lubbock, first Baron Avebury, was the son of Sir John William Lubbock, Bart., head of the banking firm of Robarts, Lubbock & Co. He was born on April 30th, 1834, and was educated at a private school and at Eton, but left school at the age of 14 to commence a distinguished career as a banker, man of business, and legislator. Many reforms were introduced by him into the banking system, and several Acts of Parliament were due to his initiation; but probably his promotion of Bank Holidays in 1871 was what appealed most strongly to public feeling. He served on Royal Commissions appointed for the consideration of such subjects as International Coinage, Public Schools Education, Advancement of Science, and Gold & Silver; while he was Chairman of the Committee which selected designs for the last coinage of Queen Victoria. When the London County Council was formed, he was elected to represent the City, and in 1890 succeeded Lord Rosebery as Chairman. From 1870 to 1880 he represented Maidstone, and from 1880 to 1900 the University of London, in Parliament. In 1900 he was raised to the peerage.

In science he proved himself to be a man of wide interests, with much power of original research. His attention was first directed to prehistoric times, as illustrated by ancient remains, and the manners and customs of modern savages; but subsequently he devoted himself more especially to observations on the social life and intelligence of insects. The results were incorporated in a work on Ants, Bees, & Wasps, which went through no less than fourteen editions and was circulated in all parts of the world. Among other of his works dealing with kindred subjects may be

[1] See Gubernatis, 'Dictionnaire International :—Écrivains du Jour.'

mentioned 'The Origin & Metamorphosis of Insects' (1874), 'On British Wild Flowers, considered in relation to Insects' (1875), 'The Senses, Instincts, & Intelligence of Animals,' 'Chapters in Popular Natural History,' and the 'Monograph on the Collembola & Thysanura.'

In Geology he was not, and never professed to be, an original observer, nor had he any technical training in that science further than could be obtained by general and intelligent reading. Perhaps the better for that reason he was able to produce what was wanted by the man whose interest had been whetted, but who was averse to taking too deep a plunge into geological speculations. 'The Scenery of Switzerland' (1896), and 'The Scenery of England' (1902), form admirable introductions to the study of physical geography, and have each appealed to a large circle of readers by the charm of their literary style and the beauty of the illustrations. His earlier geological work included a paper, read in 1867 before our Society, on the Parallel Roads of Glenroy. In 1903 and 1905, again before our Society, he described briefly various experiments in mountain-building, carried out on alternations of baize and sand which were laid under compression in two directions at right angles one to the other. In the former year he was selected by the Council as the first recipient of the Prestwich Medal, then recently established under the will of his old friend and companion in the study of Prehistoric Man.

Lord Avebury was elected into our Society in 1855, and served four times on the Council. In 1858 he was elected into the Royal Society; on seven occasions he was a member of their Council, and on three of these he was nominated a Vice-President. He became a Trustee of the British Museum in 1878, and from the first interested himself keenly in the development of the Natural History branch. As further proof of the respect in which he was held, it may be recalled that he was elected President of the British Association in its jubilee year, and at various times presided over the Entomological, Ethnological, Linnean, Statistical, African, and Ray Societies, the Anthropological Institute, the International Association for Prehistoric Archæology, the International Association of Zoology, and the International Library Association. He received honorary degrees from Oxford, Cambridge, Dublin, Edinburgh, and St. Andrew's Universities, was a recipient of the Prussian Order 'Pour le Mérite,' and a Commander of the Legion of Honour.

Lord Avebury married, first, the daughter of the Rev. Peter

Hordern, and, secondly, a daughter of the late General A. A. Lane-Fox-Pitt-Rivers, F.R.S. His pre-eminently busy and useful life was brought to a close on May 28th, 1913.

JOHN MILNE was born at Liverpool on December 30th, 1850. After completing his education at King's College and the Royal School of Mines, he obtained a brief experience as a mining engineer in Newfoundland and Labrador while working for Cyrus Field, Sir James Anderson, and others, and as a geologist while on Dr. Beke's expedition into North-Western Arabia in search of the exact site of Mount Sinai. At the early age of 25 he was appointed by the Japanese Government Professor of Geology & Mining in the University of Tokyo, and there, during his 20 years' tenure of the post, found opportunity to develop the science with which his name is more especially connected. His interest having been roused by almost daily earthquakes, he founded a Seismological Survey, establishing no fewer than 968 observing stations, and training a large body of native observers to keep him supplied with the information on which he could construct isoseismal charts. At the same time he devised recording instruments, made observations on artificial earthquakes, and studied the methods of construction which were best adapted for building in earth-shaken regions. In 1900 he was largely instrumental in founding the Seismological Society of Japan, the first association of scientific men formed for the study of earthquakes. For fifteen years he acted as Secretary thereof, and the results of his work during that period of his life fill a large proportion of the Society's publications.

In 1895 Milne retired from his professorship, and in 1900 settled permanently at Shide in the Isle of Wight. On the eve of his departure from Tokyo his home was destroyed by fire, with practically all its contents, including his books and instruments.

Immediately upon his return to this country he commenced the installation of a seismological observatory, which was destined to make Shide a centre of interest to seismologists in all parts of the world. The observations there made were supplemented by records from upwards of sixty other stations, for the most part founded on Milne's initiation and furnished with his type of seismograph. The funds required for so extensive an organization were supplied in part by the British Association, and the results of the observations were laid before that body in a series of reports which continued without interruption through a long succession of years. Latterly, the support

of the Royal Society was extended to the enterprise, the work having become recognized as being of world-wide interest.

Milne travelled widely. On receiving his appointment in Japan he proceeded to his post by way of St. Petersburg, through Siberia and China, taking eight months to reach Shanghai, and experiencing hardships which would have deterred anyone of less determined character or less sturdy physique. He had already worked in Newfoundland, Labrador, Iceland, and Arabia, and subsequently he extended his exploration to the Pacific Coast, from the Kuriles and Korea to Manila, Borneo, the Australian Colonies, and many other volcanic islands. He also visited the United States.

The results of Milne's work are recorded chiefly in the publications of the Seismological and other Japanese Societies, in the Reports of the British Association, the Transactions and Proceedings of the Royal Society, and elsewhere; but he contributed four papers to the Quarterly Journal of the Geological Society between 1873 and 1883, dealing with such subjects as the physical features and mineralogy of Newfoundland, notes on the Sinaitic Peninsula, the action of coast-ice, and the elasticity of Japanese rocks. In 1886 and 1898 respectively, he published in book-form 'Earthquakes & other Earth-Movements' and 'Seismology,' and in 1911 he laid before the British Association a Catalogue of Destructive Earthquakes, A.D. 7 to A.D. 1899, which has been published in pamphlet form.

This great record brought honours to Milne, both in Japan and at home. He was an Honorary Fellow of King's College, London. In 1887 he was elected into the Royal Society, and in 1908 received a Royal Medal. He became a Fellow of the Geological Society in 1873, and received the Lyell Medal in 1894. The Order of the Rising Sun was conferred upon him in 1895 by the Emperor of Japan. From the University of Oxford he received an Honorary Degree of D.Sc.

Milne died on July 31st, 1913. Though his career ended at the comparatively early age of 63, while he was still in active work, he had yet accomplished enough to make his name inseparable from the study to which he had devoted himself. He was one of the first to devise the means by which distant earthquakes could be recorded, and before he left Japan had constructed an instrument for this purpose, which he afterwards brought home and started to work at Shide. His suggestion that important earthquakes could be recorded in all habitable parts of the globe if suitable instruments

were provided, marks the initiation of the science of Seismology, and his seismograph, which was subsequently distributed over the world, differed only from that which he had brought home in minor details and in being of better workmanship. No less far-reaching were his researches on the distinction between vibrations which travel round the globe and those which are transmitted through it, or the practical application of his knowledge to the causes of fracturing of submarine cables, and of collapse of buildings in earthquake regions. Whether as an original investigator or as a personal friend, Milne leaves a gap which it is difficult indeed to fill.

Horace Bolingbroke Woodward was the son of Dr. S. P. Woodward, of the British Museum, and was born on August 20th, 1848. He was educated at private schools, and at the age of 15 commenced what was destined to be a distinguished geological career by undertaking the duties of Assistant in the Library and Museum of the Geological Society. In 1867 he was appointed to the Geological Survey under Sir R. Murchison, and continued in that service until December 31st, 1908, a period of 41 years, during the last seven and a half of which he was, as Assistant Director, in charge of the work in England and Wales.

At the commencement of his service, the Old Series 1-inch Geological Map was far from complete, and his work lay at first in the south-west, where he was engaged in adding detail and precision to the mapping of the Secondary Rocks, especially of the Rhaetic Beds. Later on he was stationed for many years in the Eastern Counties, where he was concerned with Cretaceous and Tertiary strata and the great development of Pleistocene deposits in that part of the country. The results of his work appeared in the Memoir on the East Somerset and Bristol Coalfields, published in 1876, and in the Memoirs on the Geology of Norwich (1881), of Fakenham (1884), and others of which he was part author.

In 1890 the Geological Survey commenced the publication of General Memoirs presenting a compendium of all that is known regarding each of the formations in its distribution throughout the United Kingdom. The task of carrying out the part of this great project that related to the Jurassic rocks of Britain (not including Yorkshire, which was undertaken by C. Fox-Strangways) was entrusted to Woodward, and before the end of 1895 there had

appeared under his name three volumes on the Liassic and Oolitic rocks of England and Wales, which alone would serve as a lasting monument to his untiring industry, his inexhaustible patience in collecting all that was worthy of note from the writings of his predecessors, and his skill in combining their materials with his own observations to make an intelligible narrative.

In 1892 his intimate knowledge of the Jurassic rocks led to his being temporarily engaged in mapping parts of the Islands of Raasay and Skye for the Geological Survey of Scotland. The account of his work in Skye is published in the Glenelg Memoir. In Raasay he was the first to recognize that iron-ores of economic value occurred in the Lias at the same horizon as the Cleveland ores, and it was due to his suggestion that explorations were started which have brought into existence an important industry.

Later he showed a marked facility for putting geological information into a form that was palatable to the general reader, in his Memoirs on Soils and Subsoils (1897; 2nd ed. 1906) and on the Geology of the London District (1909). Among less popular, but eminently useful works may be mentioned the Water-Supply Memoirs on Lincolnshire (1904) and on Bedfordshire with Northamptonshire (1909). One of his last official publications was a 2nd edition of the Geology of Sidmouth (1906; 2nd ed. 1911).

Among his published works, apart from the official Memoirs, the 'Geology of England & Wales' comes first to mind. The 2nd edition, published in 1887, 11 years after the issue of the 1st edition, was designed

'to afford a book of reference, useful not only to students of the scientific aspects of the subject, but also to engineers and others interested in its practical applications.' (*Op. cit.* p. v.)

It displays in a marked degree the power of the author to present in a small space and in a convenient form a mass of varied information collected from many sources. The author himself was too modest to realize the place filled by this book as a work of original research, but it may be claimed for him that his profound knowledge of British Geology enabled him to review doubtful propositions, and to present conclusions which in themselves constitute an advance in knowledge. In stratigraphical questions he was a master. Modern palæontology did not appeal to him: to the last he was averse to the alterations in nomenclature which are the inevitable accompaniment of increasing refinement of method, and he made no attempt to disguise his regret at the

abandonment of generic names which for him and for most of us had become classic by usage.

The list of works for which we are indebted to him is long, and I can only now mention his Geology of Water-Supply (1910), of Soils and Substrata (1912), many contributions to the Victoria County History, and his share in the preparation of Stanford's Geological Atlas of Great Britain & Ireland. We remember, too, that at our first Centenary in 1907 he successfully carried out the task, which had been entrusted to him by the Council, of writing the history of this Society. To the publications of this Society, of the Geologists' Association, of the British Association, of the Somerset and Norfolk local scientific societies, he was a frequent contributor, and for the 'Geological Magazine' he not only wrote original articles, but carried out the duties of a sub-editor for many years.

All his writing is marked by scrupulous care in compilation, and by a conscientiousness in acknowledging previous writers that threatened at times to cramp his own originality. It was to him a delight to work, and after illness had rendered impossible those visits to the field which he loved so well, he busied himself in collating, in editing, in any work indeed in which his experience could be turned to account. Almost up to the moment of his death he was engaged in preparing the statistical part of a Geological Survey Memoir on Water-Supply.

Woodward was elected into our Society in 1868 and into the Royal Society in 1896. In 1885 he received the Murchison Fund, in 1897 the Murchison Medal, and in 1909 the Wollaston Medal, awarded to him by the Council of the Geological Society in consideration of researches conducive to the interests of the science of Geology. He served on the Council several years, and was Vice-President in 1904–1906, but the state of his health prevented him from taking an active part in the affairs of the Society at the time when his services were most likely to be available. He was President of the Geologists' Association in 1893–94.

For not far short of 40 years I was associated with Woodward on the Geological Survey. As I look back upon this long period, I realize what I owe to him. As my senior officer he was sympathetic and helpful, and his example was noble. As my friend he inspired me with that affection which only perfect amiability and unselfishness can win. I can recall no harsh word, no unjustified criticism, no unfriendly action during all those years.

At the time of his retirement from the Geological Survey he had reached the age of 60, and the first symptoms of his illness had appeared. He lived five years more, working with indomitable fortitude but with gradually decreasing strength, until the end came on February 6th, 1914.

Tempest Anderson, M.D., Hon. D.Sc. (Leeds), J.P., was a member of a well-known Yorkshire family, and showed a keen interest in fostering the study of science in his native county. Born in 1846 he was educated at St. Peter's School, York, and had a distinguished career at University College, London, and at the University of London. In his profession he devoted his attention particularly to diseases of the eye, on which he published several papers, and was for some years Consulting Ophthalmic Surgeon to the York County Hospital. In his spare time he proved himself to be a capable mountaineer and travelled widely, always with the view of adding to his collection of photographs of places of interest. But his reputation as a man of science was due more especially to his photographic studies of the phenomena attendant upon volcanic eruptions and the flow of lavas. As a result of long experience in using the camera under difficulties, and often at great personal risk, he had brought his apparatus to a high degree of perfection, and by his geological knowledge had been able to select subjects, not merely of sensational interest, but of utility to students of ancient and modern volcanoes. His photographs were frequently exhibited at scientific meetings.

In 1902 Anderson was commissioned by the Royal Society to undertake a joint investigation with Dr. J. S. Flett on the eruption of the Soufrière in St. Vincent. The report, illustrated by remarkable photographs by Anderson, appeared in the Philosophical Transactions for 1903, and was followed in 1908 by a second report, in which Anderson described the changes that had been more or less permanently effected by the outburst and by subsequent erosion of the ejected material, as observed by him in 1907. In 1903 he published his well-known work on 'Volcanic Studies in Many Lands.' The material for this work had been gathered by examination of Skapta Jökull in Iceland, by more than one journey to the Lipari Islands, and by visits to New Zealand, Kilauea, Mexico, Guatemala, and Savaii.

Tempest Anderson was a valued member of several scientific societies. As President of the Yorkshire Philosophical Society he

did much, both by precept and by financial aid, to encourage a pursuit of science. The addition of a lecture-hall to the York Museum was virtually his gift. He was a Member of Council and former Vice-President of the British Association, President of the Museums Association in 1910, and a Member of Council of the Royal Geographical Society. He was elected to the Geological Society and served on our Council in 1912–13, but resigned his seat in prospect of the journey from which he was destined never to return. He contributed a paper to our Quarterly Journal in 1910 on the Volcanoes of Matavanu in Savaii, beautifully illustrated with his own photographs. In this paper, among many other interesting observations, he gave what is probably the first account by an eye-witness of the development of pillow-structure in a lava-flow on its entering the sea.

He died on August 26th, 1913, while on the homeward journey from the Philippine Islands, and was buried in the cemetery at Suez.

Donald Smith, first Baron Strathcona and Mount Royal, was the son of Alexander Smith, a Highland merchant. He was born, as he himself believed, on August 6th, 1820, but as his friends thought, in 1818. At the age of 18 he entered the service of the Hudson Bay Company, and for thirteen years was stationed at Hamilton Inlet on the coast of Labrador, where, with characteristic energy, he did what was possible to meet conditions of unusual hardship and isolation. Passing through various grades, he became Governor of the Company in 1869.

In that year the Canadian Government purchased the proprietary rights of the Hudson Bay Company, with the effect of rousing discontent among the French half-breeds and causing the Red River Rebellion. Donald Smith, with two other commissioners, was sent to negotiate with the rebels, and carried out his task with such signal success as to receive the thanks of the Governor-General in Council. From that time until 1896 he represented various constituencies in the Dominion House of Commons, closing his political career in Canada on receiving the appointment of High Commissioner in London.

Of all the great services rendered by Donald Smith to Canada none have had a more profound effect upon the development of the Dominion than the share which he took in the completion of the Canadian Pacific Railway. In 1871 a stipulation was made for the

construction within ten years of a railway connecting Eastern Canada with British Columbia, then recently included in the Dominion. The work, after the dissolution in 1873 of Sir Hugh Allan's Company to which a charter had been granted, was taken over by the Canadian Government; but little was done until, in 1880, a new contract was granted and a company formed by Donald Smith, George Stephen (afterwards Lord Mount Stephen), and others. In 1885, six years before the contract time had expired, Donald Smith drove the last spike; but for some years the company was on the verge of bankruptcy, and it was only by desperate measures on the part of Smith and his friends that it was nursed through a period of adversity and developed into one of the great transportation companies of the world.

In 1896 Smith was appointed High Commissioner for Canada in London, an office which he retained until his death. He was raised to the peerage, under the title of Lord Strathcona and Mount Royal, in 1897.

During the Boer war, Lord Strathcona gave expression to the patriotism which animated Canada, by equipping and landing in South Africa, at his own expense, a regiment of mounted scouts. The men had been connected with the North-Western Mounted Police, and by their services during the war enhanced, if it were possible to do so, the great reputation of that force.

The great influence which Lord Strathcona was able to bring to bear upon Canadian affairs, both by his position and by his wealth, was exercised with sound judgment and untiring industry. His private benefactions were on a princely scale, and in their bestowal showed a discretion and kindliness of heart which endeared him to all nationalities in the Dominion.

He was the recipient of many University honours, and, in 1904, was elected into the Royal Society of London. He had been a Fellow of the Geological Society since 1885.

He died on January 21st, 1914, having maintained his activities up to the day when the last brief illness commenced.

James McMurtrie was born at Dalquharran in Ayrshire, and there, under his father, commenced a connexion with coal-mining which was to fill a large part of his life. After spending a few years in Liverpool and Newcastle-on-Tyne in completing his training, he became, in 1862, an Assistant to Mr. G. C. Greenwell in the management of the Radstock Collieries. Later on, he

managed the Newbury Collieries, but on the retirement of Mr. G. C. Greenwell, he succeeded him in his post and occupied it for 40 years. During this period McMurtrie took a prominent part in the settlement of the difficulties which arose from time to time between owners and men, and was largely instrumental in introducing the sliding scale and in establishing a Conciliation Board. During his management of the Radstock Collieries he deepened the pits below the Radstock Series, which alone had been worked, and succeeded in winning the Farrington Series of seams, thus adding considerably to the local coal-resources.

McMurtrie was elected a Fellow of the Geological Society in 1873. Although he did not contribute to our Journal, he made his profound knowledge of the Somerset Coalfield available in other ways. Sir Joseph Prestwich, in his report on the coalfield to the Royal Coal Commission of 1871, included a valuable section drawn by McMurtrie to illustrate the relative positions of the productive strata, the form of the coalfield, and its extension beneath the Mesozoic formations. Thirty years later McMurtrie contributed a tabular statement of the sequence of strata near Radstock to the Royal Commission on Coal-Supplies, which reported in 1905.

Other papers relating to the geology, archæology, and mineral resources of the district that he knew so well, appeared in the publications of the Somerset local scientific societies, in the Reports of the British Association, the Transactions of the Institution of Mining Engineers, and the Proceedings of the South Wales Institute of Engineers; of the last-named Institute he was President in 1879–81. A valuable collection of fossil plants from the Coal-Measures of Somerset was made by McMurtrie, and was referred to by Morris in the 'Geological Magazine', vol. v. It was presented to the British Museum in 1894, and is now exhibited among the Natural History collections. McMurtrie died on February 2nd, 1914, at the age of 74.

Henry Franklin Parsons, M.D., was born on February 27th 1846. He was educated at private schools and at St. Mary's Hospital, subsequently enjoying a distinguished career at the London University, where he gained the Gold Medal in Physiology, Histology, & Comparative Anatomy in 1865, and that in Public Health in 1876. After six years of medical practice, he was appointed Medical Officer of Health for the Goole and Selby district of Yorkshire in 1874, and was made a Medical Inspector

at the Local Government Board in 1879, a post which he retained until 1892, when he became Assistant Medical Officer. In 1911 he retired from official life. Parsons manifested an interest in geology from an early age, and was elected to the Geological Society in 1877. Though he never contributed a paper to this Society, he rendered valuable assistance to the Geological Survey by supplying records of wells in all districts with which he was connected, and was part-author of the Memoirs on the Water-Supplies of Suffolk, Lincolnshire, Sussex (Supplement), and Kent. He served on several interdepartmental Committees, and among them on one appointed to enquire into the work of the Geological Survey.

He was the President of the Epidemiological Society, and was author of many reports on medical and sanitary subjects.

Dr. Parsons died on October 29th, 1913.

James Logan Lobley was born in 1833, and was elected a Fellow of the Geological Society in 1865. He was author of a small work on Mount Vesuvius in 1868, and brought out an enlarged volume under the same title in 1889. He contributed but little to the Journal of this Society, but wrote more frequently in the Geological Magazine. His main energies, however, were devoted to the Geologists' Association, in which he held office for fourteen years. In his later years he was engaged, under the auspices of the Royal Geographical Society, in teaching the elements of geology to explorers. In June 1913 he was awarded a Civil List Pension, but on the 27th of that month he died, only a few days before the announcement was to reach him.

Sir James Lamont was best known to geologists of a former generation, in connexion with his work in the Arctic regions. Undertaken primarily for purposes of sport, his voyages resulted in his publishing in 1871 and 1876 contributions of much value to the little that was then known of Spitsbergen and Novaya Zemlya. After completing his education at Rugby and the Edinburgh Military Academy, he served for two years in the Army, and for three years he represented Buteshire in Parliament. He was elected into our Society in 1859. He died on July 29th, 1913, at the age of 85.

William Henry Sutcliffe, who was born in 1855, received his education at Manchester Grammar School and Owens College. Though engaged in business as a cotton manufacturer, he was energetic in the investigation of the archæology and geology of his own neighbourhood. The remains of Prehistoric Man to be found near Rochdale excited his keenest interest, and the collections made by him are a notable feature in the museums at Rochdale and Manchester University. Possessed of a keen critical faculty, he found himself unable to accept the authenticity of 'Eoliths,' or the postulated antiquity of the Galley Hill and Ipswich skeletons.

As a collector of fossils his services have proved of great value, more especially in elucidating the fauna and flora of the Coal Measures.

Mr. Sutcliffe was elected a Fellow of the Geological Society in 1903, and in 1904 contributed to the Journal a joint paper on *Eoscorpius sparthensis*, sp. nov. He was a member of several local societies, and in 1912 President of the Rochdale Literary & Scientific Society. He died on August 18th, 1913.

Philip Lutley Sclater was born on November 4th, 1829. He was educated at Winchester and Oxford, and in 1855 was called to the Bar. The study of ornithology, however, proved more attractive than that of law, and led to Sclater becoming one of the most noted zoologists of his day. His connexion with the Zoological Society extended over a period of 63 years, during 43 of which he served as Secretary.

Sclater's division of the earth's surface into regions based on the distribution of birds, though not now adopted in its entirety, served usefully in its time to direct the labours of geologists who were studying the past distribution of animals. These regions, however, were regarded by him as separate centres of creation; it remained for Darwin and Wallace to explain the distribution of life.

Sclater was elected into the Royal Society in 1861, and into the Geological Society in 1878. He died on June 27th, 1913.

Frank Johnstone Mitchell, who was elected into our Society so long ago as 1859, was educated at St. John's College, Cambridge, and was professionally engaged at Newport (Monmouthshire). Antiquarian research proved to be the main occupation of such time as he could spare from business.

He died on October 11th, 1913, at the age of 90.

HERBERT KELSALL SLATER, son of the Rev. T. E. Slater, a missionary in Mysore, was born on August 28th, 1875. He was educated at Bishop's Stortford College and the Central College, Bangalore. In 1894 he received an appointment in the Mysore Geological Department; but in 1901, and again in 1909, he returned temporarily to England in order to study those branches of geology in which his professional duties lay.

The record of work which he has left in the publications of the Mysore Geological Department, proves that by his death we have lost one of the most promising of the younger geologists. The last number, published since his death, contains a map and report by him on crystalline rocks comparable to the Keewatin formation of Canada.

He had been elected a Fellow of our Society in 1902.

On May 2nd, 1913, while in camp in the Shimoga District, Slater trod upon a venomous snake and was repeatedly bitten. He died about twelve hours later.

THOMAS HENRY COPE, Managing Director of the firm of Messrs. Cope Brothers, tobacco manufacturers, was an assiduous student of geology, and devoted much attention to the volcanic rocks of North Wales. He was elected into the Geological Society in 1905. On April 28th, 1913, he died at the early age of 46.

RUSSELL FROST GWINNELL was elected into this Society in 1903. He was engaged as lecturer at the Imperial College of Science, South Kensington, and his life came to a premature end on March 15th, 1913.

In addition to the losses from the ranks of this Society to which I have referred, we have to deplore the deaths during the past year of two workers of notable originality in the physical and biological branches of geological science.

GEORGE HOWARD DARWIN, by profession an astronomer, was engaged for many years in calculations of far-reaching importance on the age and history of the Earth and its satellite. His first paper on a geological subject, published in 1877, was devoted to testing the theory that glacial epochs could be explained by a wandering of the pole in the Earth's figure due to geological earth-movements together with associated changes in the obliquity of the ecliptic. His conclusions, to quote his own words, were

'absolutely inconsistent with the sensational speculations as to the causes

and effect of the Glacial Epoch which some geologists had permitted themselves to make.'

Turning his attention to the age and history of the Earth, he proceeded to investigate the frictional resistance experienced by a tidal wave, and formed some important conclusions as to the rigidity of the Earth as a whole, and as to the cumulative effect of attractive forces acting on the parts of the Earth nearer to and farther from the disturbing body.

While unable, with existing evidence, to form an estimate having any pretension to accuracy as to the present rate of tidal friction, yet he was able to infer a gradual increase in the length of the day, of the month, and of the obliquity of the ecliptic with a gradual recession of the Moon from the Earth. He further calculated that at a distance of time of not less than 54 million years, the Moon's centre would have been only about 6000 miles distant from the Earth's surface, while the day and the month would be of equal duration, estimated at 5 hours 36 minutes. The further inference followed that the Earth and the Moon had once formed a single mass. Such a mass, gaining in rapidity of rotation as it contracted, had split into two, and, according to his investigations of the motions which would follow upon such a rupture, must have developed a system bearing a strong resemblance to our own.

Darwin then turned his attention more especially to the stresses caused in the interior of the Earth by the weight of continents and mountains, and found reason to believe that resistance to these stresses implied a strength of material at least equal to that of granite.

Alfred Russel Wallace was born on January 8th, 1823. At an early age he was attracted to the study of botany, but later on became engrossed in entomology. This led to a journey to the Amazon and Rio Negro, on the return from which his ship, with all his collection, was destroyed by fire in mid-ocean, and his health was temporarily shattered by exposure for ten days in an open boat. In 1854, after his recovery, he visited the tropics, and made the observations in Borneo, Sumatra, Java, the Celebes, New Guinea, and Singapore which enabled him to produce his classic work on the 'Geographical Distribution of Animals' and his more popular account of 'Island Life.'

During these years Charles Darwin had been engaged in collecting the facts on which his theory of natural selection was based. So far back as 1844 he had outlined his views to Lyell and Hooker, and had been urged by Lyell to publish them, lest he should be

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forestalled. Determined, however, that his conclusions should be well-founded, he had continued his patient preparation of evidence.

Wallace at that time had, by his own account, 'hardly thought of any serious study of nature.' The idea of natural selection came to him while he was at Ternate, in the Malay Archipelago, in a sudden flash of insight. In a week it was written out and sent to Darwin. Darwin, forestalled after 20 years of work, maintained that Wallace was entitled to an equal share with himself in the honour of the discovery; Wallace himself considered that his share might be estimated in the proportion of one week to twenty years. In 1858 joint papers by Darwin and Wallace, 'On the Tendency of Species to form Varieties, & on the Perpetuation of Varieties & Species by Natural Selection,' were communicated to the Linnean Society. This, briefly, is the story of the birth of a theory on which modern biology and palæontology are based.

Both the great men who took part in this contest of magnanimity have now passed away, but before his death Wallace received proof of the high value which was to be attached by posterity to his work and to his share in the discovery.

One of the subjects touched upon by Wallace was an estimation of the age of the Earth. In discussing calculations founded on the length of the stratigraphical column, he pointed out that, although denudation proceeds on all exposed land-surfaces, deposition is confined to the coastal parts of the oceans, and is correspondingly more rapid. After careful consideration of the limits of the area within which the degraded material may be assumed to be distributed, he inferred that

> 'deposition, as measured by *maximum* thickness, goes on at least nineteen times as fast as denudation.'

On the strength of this conclusion he advocated a large reduction in the estimate of time required for the deposition of the strata of the world. The conclusion may be well-founded, but it helps little if our knowledge of the rate of denudation is confined to mere guesses; and it must be admitted that our knowledge, not only as regards the rate at which any one of the many types of existing land-surface, but, still more, the land-surface of the globe as a whole, are being degraded, deserves no better description.

Problems of Post-Glacial Denudation.

The problem of denudation, in all but the latest geological period, is one of infinite difficulty, for it involves consideration of varying conditions which can never be known. The distribution of different types of rock in the land-surface of past ages can only be ascertained locally and imperfectly; yet their power of resistance is a dominant factor in the problem. The vagaries of climate are not calculable now, and are past guessing in former geological periods. The tropical climate, with extremes of temperature and spasmodic rainfall, the wet climate, the dry climate with persistent wind, are a few of a long list of types, each intensely active. That they existed in past times we know, but of their distribution and duration we know next to nothing. Nor is it possible to estimate the protective or destructive effects of the organic life of land-surfaces of geological times.

An estimation of the effects of denudation during the latest geological period, though beset with difficulties, is less open to these objections. Indeed, it seems evident that geologists should prove the possibility of forming an estimate with some degree of precision for that period during which conditions not widely different from those now existing prevailed, before aspiring to furnish statistics for primæval times. I propose, therefore, in dealing with the question of denudation, as evidenced in this country, to confine my remarks to post-Glacial time, to consider what methods are possible of estimating the amount of denudation which has been effected during that period, and of measuring the rapidity with which the denuding agents are now carrying on their work. Without suggesting that those agents have been uniformly effective during the changing conditions which have prevailed in post-Glacial time, we may claim that they have operated under conditions so comparable with those of the present day, as to bring their effects within the range of legitimate speculation.

The problem of post-Glacial denudation is open to attack from more than one direction. We have no such sensational example in the British Isles as the gorge of Niagara, but we can show a well-developed series of Glacial deposits, which have been under close and prolonged observation. In proportion as we have learnt to distinguish these from the various gravels that have been formed out of their waste, we have become the better able to recognize topographical features of post-Glacial origin. River-gorges, re-excavated

pre-Glacial valleys, and dissected plateaus are some among the many forms in which the effects of post-Glacial denudation are presented for consideration.

In this connexion, I leave out of account the weathering of the rock-surface itself, as being too indefinite a factor to furnish a calculation for the present purpose. In some districts the effects of glaciation are displayed in such freshness as to suggest that the Glacial Period is an episode of yesterday; elsewhere the surface has so perished as to leave merely a reminiscence of the forms characteristic of glaciation. Much has depended upon the character of the rock and of the climate, but no less on the nature of the material by which the rock was covered and the length of time during which the surface has been exposed to the air. Attempts have been made also to determine the relative ages of Glacial deposits by the amount of weathering, as distinct from erosion, which they have undergone. But I put these effects aside, as yielding no data suitable for my present purpose.

Such objections apply in a less degree to the removal of Glacial deposits by the ordinary agents of denudation. There are regions where it is not only possible to trace the evolution of the existing landscape, but where there would seem to be a possibility of estimating the bulk of the material removed in the process of evolution. The work has been done by streams and other agencies now in operation. The next step, therefore, would be to ascertain the rate at which those agencies are working, in order to calculate the time required for the removal of the material under existing conditions. How far these conditions have varied would still remain for consideration.

I can best illustrate my meaning by mentioning examples where measurements of post-Glacial work may be within reach. One such case occurs on the Welsh Border in Denbighshire. There a plateau of Glacial sand and gravel extends eastwards from the Welsh hills for 2 or 3 miles. It ranges from 250 to 300 feet above the sea, and terminates eastwards in a somewhat steep declivity, from the foot of which extends a broad plain of Boulder Clay with a height of about 50 feet above the sea.

The River Alyn, leaving the Welsh hills, crosses the plateau and the Boulder-Clay plain. At first it descended the declivity, as we may suppose, by a series of rapids, but for a short time only—for in the loose gravel cutting-back must have commenced at once. At the present day, the river has established a course of fairly steady

gradient, traversing the declivity in a steep-sided valley which has perhaps an approximate average depth of 100 feet and a width of a quarter of a mile. Here, therefore, appears to be a post-Glacial excavation, of which the capacity may be measurable.

The river, however, on reaching the Boulder-Clay plain was greatly weakened in transporting power, and was unable to roll its burden of gravel farther. The contents of the gorge were consequently shot on to the low ground and there spread abroad. The fan thus formed extends outwards from the foot of the declivity for about 2 miles, and occupies an area of between 3 and 4 square miles. It will be seen that the cubic contents of the delta, *plus* the amount of fine sediment which the river could carry off in suspension, should equal the cubic capacity of the gorge.

I have mentioned this case, not because I have founded any calculation upon it myself, but because it forms an example where two estimates could be made, and checked one against the other. It will be remembered that a calculation of the amount of material removed by the Dee under similar circumstances, in the process of excavating its post-Glacial valley below Cefn Viaduct, has been made by Mr. Wills in his paper on 'Late Glacial & Post-Glacial Changes in the Lower Dee Valley.'[1] If the Alyn gorge were to be used for the purpose of estimating post-Glacial time, the rapidity with which the river is now working, and has worked in the past, would have to be determined and estimated. It is still adding to the delta, but its operations are increasingly retarded by the fact that it has cut down to the rock in several places, and that its gradient becomes less steep in proportion as excavation proceeds.

There are, moreover, many deltas throughout the country which might furnish data for estimating the rate at which denudation is proceeding. Many of them are being formed contemporaneously with alluvial deposits and inosculate with them in such a way as to be partly inaccessible for measurement, while others are being pushed forward under water. Deltas of the former kind abound, but become specially noticeable where a tributary enters a steep-sided flat-bottomed valley. In the Vale of Neath, a deep trench which traverses the South Wales coal-field from north to south, every tributary stream has shot its delta on to the alluvial meadows. For the most part these gravel-fans present a symmetry and an appearance of finish, as though they had ceased to grow. They are clothed, too, with vegetation, and even partly built over, but it is only

[1] Q. J. G. S. vol. lxviii (1912) p. 188.

necessary to examine the raw and freshly-deepened channels of the streams which have formed them, to realize that the mechanism by which they have been spread is still in active operation. In one case the proof is particularly interesting. A delta occupying about an eighth of a square mile has been spread on to the alluvial flat by a stream which drains a tract of mountain-land. The stream is now carried across the Great Western Railway at Resolven Station in a broad iron trough. In time of flood, gravel and large stones are rolled in procession along the trough and, without some help from the railway officials, would speedily block the passage. Here there would seem to be an opportunity of ascertaining the amount of material which is being added to the delta in any given time from a known area by a stream of measurable flow.

In numberless other cases throughout the British Isles it would be of value for our present purpose to determine the relation between the size of the delta and the discharge of the stream which has formed it, for various types of geological formations.

Of deltas formed under water there is no lack in the lakes of the British Isles. Many varieties are presented, but the simplest perhaps are those formed where a stream enters at the head of a lake and escapes at the foot, dropping its solid contents and levelling up the lake-depression systematically from the head downwards. Others which have been pushed out from a fairly straight and regular shore-line present opportunities of measurement. Less suitable for our present purpose are those formed where the exit of the stream is close to its entry, or where a large feeder has thrown a bar across the foot of the lake, as has happened where the Treweryn enters the depression in which lies Bala Lake.

Other types of lakes are furnished by the innumerable meres which occupy hollows among drift-mounds, notably in Cheshire and Shropshire, but in many other parts of the country also. Few of these are entered by large streams, and they are being filled for the most part by rainwash from the neighbouring slopes and wind-borne material from far and wide. The post-Glacial sediments in them are not easily distinguished from the material which forms their original sides and would be difficult to measure, but it is probable that in some cases an estimate of their bulk would be possible. Measurements in such cases would furnish data bearing on the action of rain and wind, as distinct from the rough and ready methods of a river.

Time is an unknown factor in all the cases to which I have

referred, but there are many examples of artificially dammed-up waters which provide opportunities of measuring the amount of material transported from a known area in a known time. Mill-dams are the least satisfactory for the purpose, inasmuch as a part of the stream only is diverted to the reservoir. In flood-time, when practically all the work of the river is done, no record is preserved of the material which is rolled or carried down the main stream.

But there are many ornamental waters and reservoirs for various purposes through which the whole stream passes, and in which the entire burden of solid impurities is intercepted. Indeed, works are constructed for the express purpose of clearing water of suspended matter; yet, although the amount of water passing and the rainfall have been generally observed, the bulk of the solid contents of the water has seldom been measured, possibly from motives of discretion.

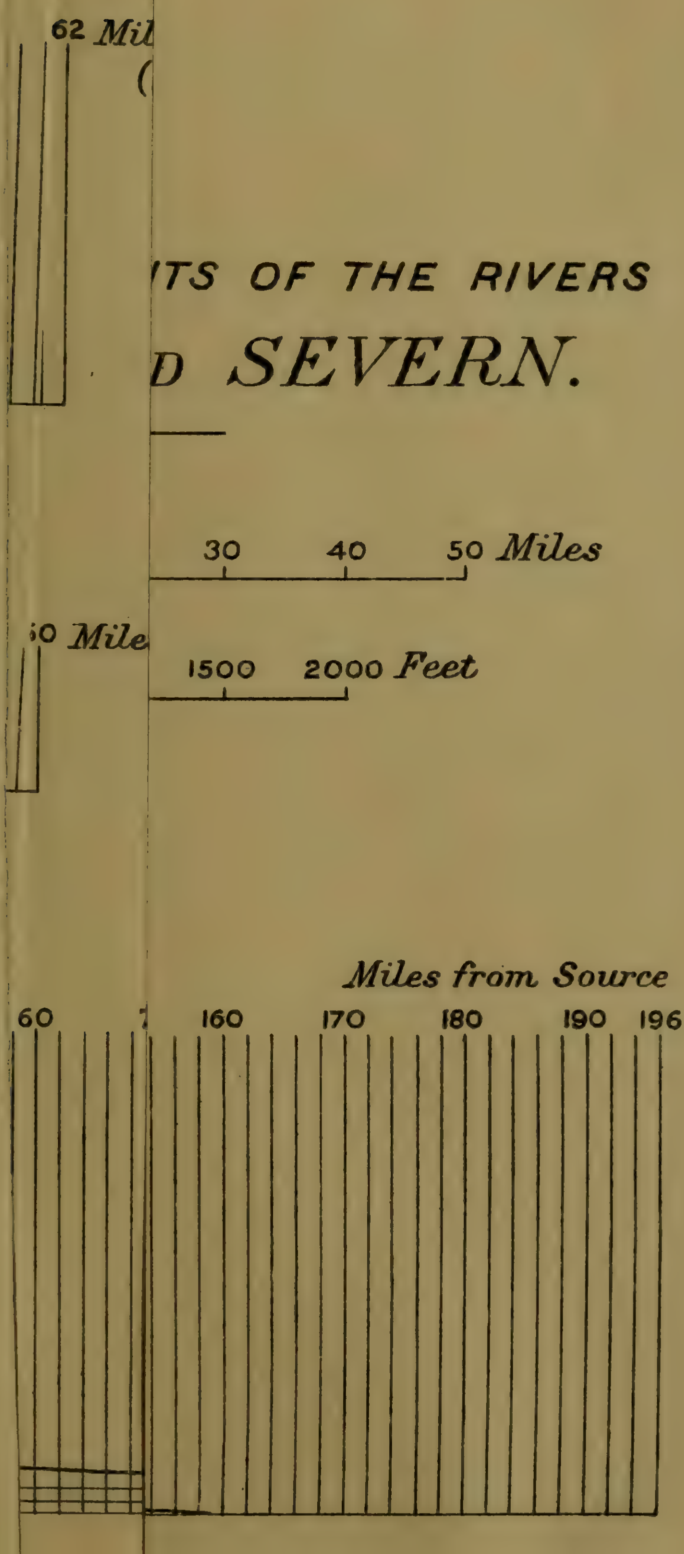
Under this head, also, may be placed rivers controlled by weirs. An example will be referred to later in a description of some experiments on the Exe, where the amount of material removed from the channel annually above a dam, in order to keep the channel at a constant depth, has been recorded. Canalized rivers present a different problem. In normal weather the water is held up at a uniformly low gradient by a succession of weirs. Its power to roll material along the bottom is obviously annulled, and its ability to keep matter in suspension greatly diminished. It would appear at first sight that the river must be paralysed as a denuding agent. That this is not the case is clear enough during the passage of a flood. Weirs at such times are thrown open, or may even be so deeply submerged as to play the part of mere rugosities in the channel. The power of a river at normal level to roll material is probably negligible, whether canalized or free; its power in flood-time is apt to disregard control. At such times holes are dug in one part or another of the bed, shoals are formed in others, but always with the result of transporting material a stage farther down the valley. These effects are counteracted by dredging. Obviously then, a canalized river should provide unusual opportunities for ascertaining the rate at which material is transported by rolling. The amount dredged between each pair of weirs should, in the course of years, give an accurate account of the activity of the river in every part of its canalized course.

The distance over which rivers are now rolling coarse material is, I believe, not beyond the reach of actual observation. An examination of the stones in the recent gravels and alluvium of a river

which traverses outcrops of easily recognizable rocks should give a clue to the distance over which the coarser débris is being transported, due regard being paid to the fact that calcareous rocks are apt to disappear by reason of their solubility. My impression, founded on limited observations, is that in the majority of English rivers the distance is trifling as compared with the length of the river.

Few rivers roll material directly into the sea; in fact, no English river is now accomplishing this feat. The conditions for its accomplishment involve a continuously steep gradient down to tide-level. In our rivers the steep gradient is generally confined to the upper reaches; a modified gradient, with correspondingly reduced transporting power in the current, characterizes the middle reaches; while in the lower reaches transportation is replaced by deposition. This condition is due partly to the fact that the river-system has gone far towards reaching what is known to physiographers as 'maturity,' but still more to the sinking of the land which has taken place during and since Neolithic times, and has had the effect of drowning the lower reaches and admitting the tide far inland. A restoration of the land to the level recorded in the Neolithic deposits of the Barry and Southampton Docks and in the buried peat-beds of many other estuaries, would go far towards excluding the tide from the lower reaches; but a further elevation would be required to bring about that 'rejuvenescence' which would render our rivers capable of carrying their coarser solid contents clear out to sea.

The diagram of the Exe, the Medway, and the Severn facing this page illustrates two types of English river. The points of intersection of the river-bed with the contours shown on the Ordnance maps are plotted at their proper respective distances from the source, the scales being so adjusted as to give a vertical exaggeration of about 105. The Medway and the Severn show a profile which may be taken as typical of English rivers. Tidal waters extend about a third of the total length of the river. A long stretch of gentle gradient follows, increasing in steepness steadily, but with almost imperceptible slowness. Then comes a sudden curve up to the source. Such profiles tell their own tale. Whatever rapids or waterfalls may once have existed, all have eaten their way back to form part of the upper and steeper reaches, leaving behind them an evenly graded channel. In the Exe the case is different; the tidal reach is comparatively short, the middle reach is not only steeper, but is not perfectly graded. The upper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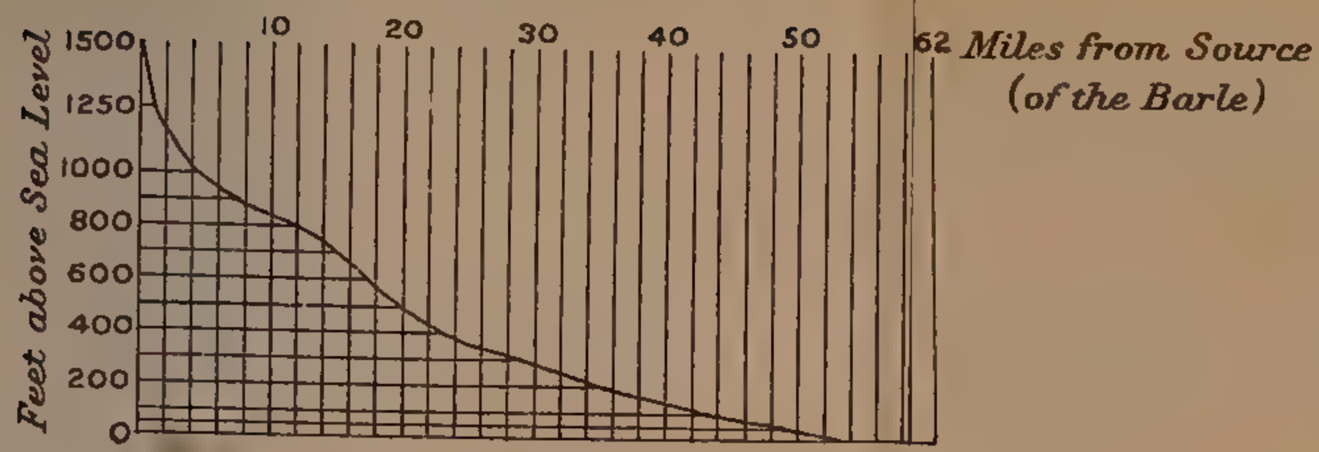
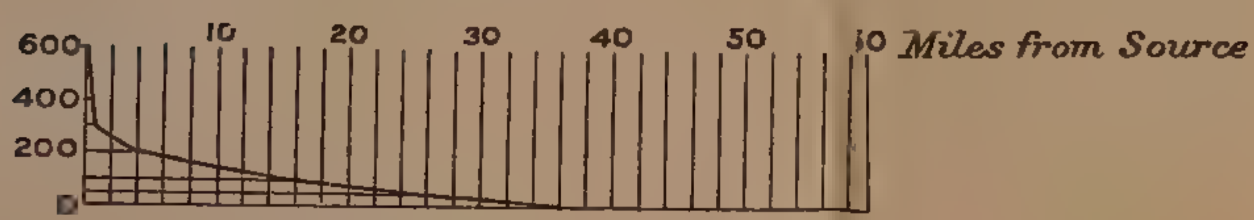
EXE

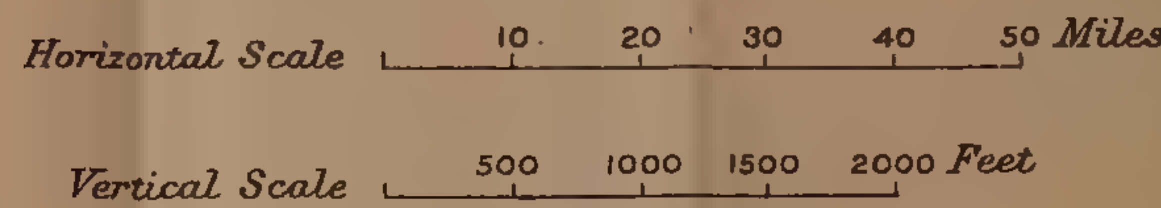


MEDWAY

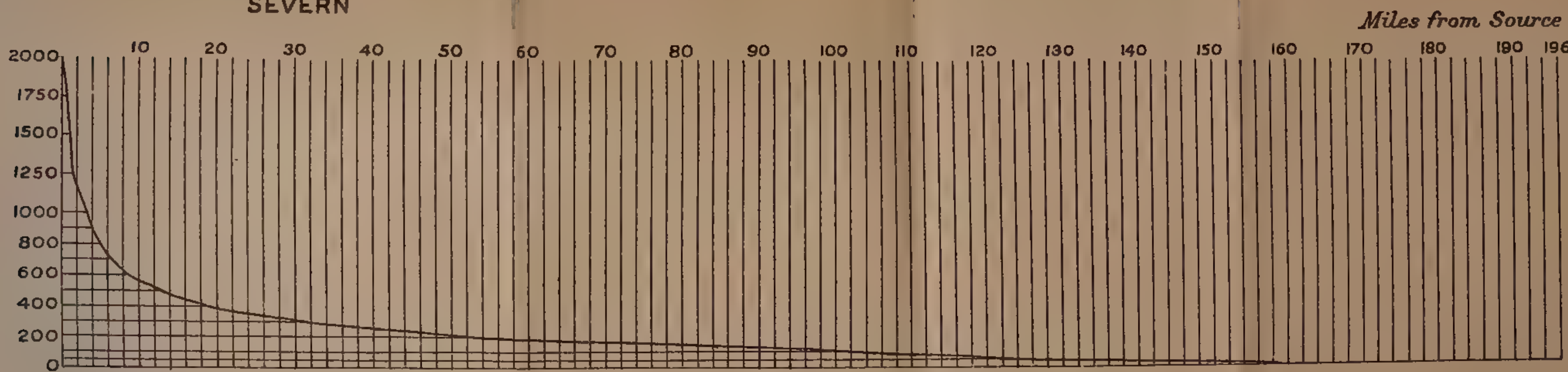


PROFILES SHOWING GRADIENTS OF THE RIVERS

EXE, MEDWAY AND SEVERN.



SEVERN



reach alone presents the characteristic form, and evidently there is still much to be done in the middle and lower reaches before such perfection of profile as that of the Severn is attained.

The power of rivers to roll material doubtless varies in different parts of their courses according to local circumstances, but the general rule holds good that the upper reaches of English rivers form the scene of erosion, and the lower reaches that of deposition. It would be interesting, in the case of the Exe, to ascertain how far the geological structure is responsible for the imperfection of the gradient; and secondly, by observing the operations of the river at several points, to determine what progress is being made towards the perfecting of it. I will now merely mention that the whole of the upper part of the course is in Devonian rocks, and that the irregularity in the gradient between 900 and 400 feet may be connected with the character of the strata at Hawkridge. The cessation of the steep gradient at 400 feet marks the spot where the river leaves the Devonian, and flows on to the Culm Measure outcrop.

In 1906, with the object of determining the rate at which denudation is now proceeding and other matters, I commenced an investigation on certain English rivers. The idea was suggested by Sir Archibald Geikie's address to Section C of the British Association at the Dover meeting in 1899, and the investigation has been carried on by the aid of the Royal Geographical Society and of a Government Grant from the Royal Society.

The investigation necessitated observations under five distinct heads, and for an account of the subdivision of labour among the volunteers who gave their services I must refer you to the reports which have been issued from time to time in the 'Geographical Journal' and to the final report on the results, which is now in preparation. The five heads referred to are:—

(1) The discharge of the rivers.
(2) The suspended and dissolved impurities in the water.
(3) The rainfall.
(4) The area of the river-basins.
(5) The character of the rocks.

The objects having a direct geological bearing were a determination of the amount of suspended and dissolved impurities carried *per annum*, and a comparison of the conditions observable in rivers draining calcareous and non-calcareous districts, or pervious and impervious formations.

It proved, in the first place, far from easy to find rivers suitable for the investigation. The rivers draining into the fens were found to be too difficult to gauge. They have a number of outlets, and the discharge is effected largely by artificial means. Accessibility was an important consideration, and in the Thames, which for this and other reasons was the first to come to mind, the natural conditions are altered, more completely perhaps than in any other river, by canalization.

Eventually, the Exe and the Medway were selected as rivers of strongly-contrasted types. The Exe drains a hill-district largely composed of Palæozoic rocks, and may be described as a clear and lively mountain-stream; the Medway drains a comparatively low tract of Mesozoic rocks, and may be described as a sluggish lowland river. The Exe for the most part is uncontrolled by weirs; the Medway is canalized. Subsequently the Severn, another canalized river, was added to the list in consideration of its importance among British rivers, and of the fact that an elaborate series of unpublished gaugings was available for our use.

The methods of measuring the discharge are described in our reports, and need not now be mentioned further than to say that they were based on a determination of the relation between the level of the water and the velocity of the current. Similarly, it was sought to establish a relation between the suspended and dissolved impurities and the level of the water. The level was therefore observed daily, and even hourly in time of flood, throughout the period of investigation; and, from these observations, the annual discharge and the amount of impurity proper to any discharge were estimated.

Arrangements were, therefore, made for the determination of the suspended and dissolved matter in samples of water collected in all conditions of the rivers. This work, which was undertaken by the chemical instructors of institutions in Exeter, Chatham, and Worcester, proved arduous, for the seizing of the proper moment for the collecting of samples was found to be essential, especially in the case of the Exe, a lively and sensitive river subject to rapidly changing moods. Special journeys were undertaken in the hope of catching a flood at its height, but were often not attended with success. Notwithstanding these disappointments, and despite the difficulty that the chemists could not allow the work to interfere with their professional duties, enough was done by them to show that here we have a subject well worthy of precise and continued

observation. The transportation of material by rolling along the bottom was dealt with in a different way. Various devices have been suggested for determining its amount, and among them I may mention a form of box-trap so constructed that it retained all the gravel which the current might roll into it. By placing this on the bottom of the river, it was believed by the inventor that an estimate could be obtained of the amount of gravel travelling. Such devices inspired me with profound mistrust—the initial error appeared likely to be enormous, and it might be indefinitely increased if the observations on a single spot were to be applied to the length and breadth of the channel.

We were fortunate, however, in obtaining, through the kindness of the City Surveyor of Exeter, some highly significant records of dredgings. The dredging has been conducted for several years in a length of the river close above Exeter, which is held up at a constant level by a weir, and is kept at a constant depth as a bathing-place by removing the gravel as fast as it accumulates. It may be assumed that no gravel is rolled over the weir. The amount dredged, therefore, is the amount which the river has rolled on to this part of its course. The records show that in the seven years, 1904–10, 8071 cubic yards were dredged.

Observations on the rainfall were provided by Dr. H. R. Mill, Director of the British Rainfall Organization. The data upon which calculations of the total annual fall are based consist of a large number of daily observations on rain-gauges scattered quite irregularly throughout the catchment-areas. Different methods of dealing with this raw material will be presented by Dr. Mill and Dr. Owens in our Report, and I will now merely point out one of the most obvious difficulties that had to be met. For the keeping and reading of a gauge the volunteer services of a resident are enlisted, but residents are apt to congregate in the most habitable parts of a catchment-area and to avoid the moorlands. It thus happens that the records from the valleys and lower reaches far outnumber those from the uplands and upper reaches. Yet it is upon the latter that the greater part of the rain falls. If, therefore, the average rainfall were calculated from the gauge-records without taking into account the distribution of the gauges, a most serious underestimate would ensue.

For the determination of the limits of the river-basins it proved necessary to examine the ground. The only map of river-basins that was useful, is one published by the Ordnance Survey many

years ago, on the scale of 10 miles to the inch. The areas of the basins are given, but they include the ground which drains into tidal water, whereas for our purpose it was necessary to exclude that part of each basin.

In practice, the precise determination of a water-parting proved to be far from easy. For example, where a plateau, such as that which dominates the landscape in the south-eastern part of Devon, has been dissected by a system of streams, the water-partings run along surviving strips of the plateau, which may range from a few yards to a mile or two in width. The strips are flat-topped, and their drainage is usually artificially effected and liable to be changed. In the case mentioned much of the plateau is formed by gravel, which rests on an inclined plane of impervious strata. The water which soaks into the ground breaks out as springs on the side towards which the plane inclines, and is far from being equally divided between the drainage-systems on either side of the plateau. There is much ground also where, for other reasons, no definite line can be drawn, and in all such cases it is better to adopt an arbitrary line than to aspire to an impossible precision. All this notwithstanding, a river-basin map of sufficient precision for practical purposes is possible, and it might well be made both for academic and for administrative reasons.

The main water-parting once determined, it became possible to make such other measurements within the basin as were desirable: such, for example, as the areas lying above 1000 feet, or between 1000 and 500 feet above the sea.

Lastly, the character of the strata cropping out within each river-basin was considered. Unfortunately the greater part of each of the three river-basins lay outside the area to which the mapping of the Drift and the revision of the solid geology by the Geological Survey has extended. It was necessary, therefore, to have recourse to the Old Series Geological Maps, and to generalize somewhat broadly on the distribution of Drift, and on the relative areas occupied by pervious or impervious subsoils.

The geological results of the investigation, with which alone we are concerned in this Society, were fairly in accordance with expectation. The amount of suspended matter was not measurable, or was extremely small, when the current was normal or below normal. It increased rapidly when the river, in rising, reached a certain level; but the rise in the amount was not always in direct relation to the rise in the water-level. We had invariably before us

the danger that muddiness in the water might be due in part to human interference. Moreover, our experiments were not sufficiently exhaustive to show whether the same proportion of suspended matter was to be expected with the same velocity of current, and whether the amount was the same with a rising as with a falling river. The dissolved matter, on the other hand, was expected to reach its *maximum* when the river was at its lowest, and was being fed by springs; it was expected to be at a *minimum* when the river was in flood, and was being fed by rain-water flowing directly off the surface of the ground.

Some of our diagrams confirmed these anticipations. In the Exe especially, a river which is more nearly than the others in a natural condition, the curves representing suspended and dissolved matter varied inversely with considerable regularity. In the Medway the diagram was impaired by our comparative failure to secure a continuous record of the discharge of water.

The Severn observations showed anomalies, which we could only attribute to artificial interference in its course through a populous region. A remarkable record, which could not be thus explained away, was obtained by Dr. Woollatt during a period of frost and thaw with snow. The proportion of suspended matter was extremely high at the commencement of the snowfall, which was accompanied by heavy rain. Subsequently, while the snow was disappearing, the proportion became abnormally low and so continued until normal conditions were restored.

The experiments, which I have here mentioned briefly and only so far as they have a geological bearing, will be described in full in the publications of the Royal Geographical Society. They were undertaken with the hope of ascertaining what ought to be done, and what it is possible to do, in the investigation of the phenomena which arise in a given area from the precipitation of water in the form of rain and its discharge in the form of rivers. In any future investigation, the five heads under which we carried out our work must form the basis of operations. Two only are provided for, namely, the 'Rainfall' by the British Rainfall Organization, and the 'Character of the Rocks' by the Geological Survey; for the other three additional organization would be required.

The importance which is attached to hydrographic surveys in other countries is due to the fact that much of the ground covered

is imperfectly known and sparsely inhabited; the water-resources, using the expression in its widest sense, are as fit a subject for exploration as are the geography and geology. In our own country the rivers have been under observation for centuries, and some sort of understanding was long ago reached between the mill-owners and the navigation companies on the one part, and the Spirit of the Flood on the other part. For this reason I am not prepared to argue that investigations such as ours must be continued on the ground of utility, so far as regards all five heads of the enquiry. In fact, I believe that the determination of the discharge of some of our rivers is practically impossible. But if any of the suggestions that I have put forward lead to more systematic and precise observations on the work of denudation, as now proceeding before our eyes, I shall have attained my purpose.

This afternoon I occupy this chair as your President for the last time. During my two years of office I have had opportunities of realizing, both at home and abroad, how great and how world-wide is the reputation of this Society. In leaving office I express the hope that that reputation is at as high a level as I found it, and in handing over the duties and responsibilities of the post to Dr. Smith Woodward, I have full confidence that it will be safe in his keeping. It is true that the two years have given me additional work, but thanks to the courtesy and assistance which I have received from the Officers and Council, and to the consideration with which I have met at your hands, they have brought me much additional pleasure.

February 25th, 1914.

Dr. A. Smith Woodward, F.R.S., President,
in the Chair.

Eric G. Brown, B.Sc., Oficina del Ingeniero Seccional, Bartolomé Mitre 299, Buenos Aires (Republica Argentina); and Vivian E. Robson, B.Sc., Assistant Curator in the Geological Department of the Bristol Museum, 41 *a* Ravenswood Road, Redland, Bristol, were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communications were read:—

1. 'Acid and Intermediate Intrusions and Associated Ash-Necks in the Neighbourhood of Melrose (Roxburghshire).' By Rachel Workman McRobert, B.Sc. (Communicated by E. B. Bailey, B.A., F.G.S.)

2. 'Correlation of Dinantian and Avonian.' By Arthur Vaughan, M.A., D.Sc., F.G.S.

Rock-specimens and lantern-slides were exhibited in illustration of Lady McRobert's paper.

Lantern-slides were exhibited by Dr. A. Vaughan in illustration of his paper.

The following map was exhibited:—

Geological Survey of England & Wales: 1-inch map, Sheet 350 (new series), Torquay, 1913, presented by the Director of H.M. Geological Survey.

March 11th, 1914.

Dr. A. Smith Woodward, F.R.S., President;
and afterwards Dr. H. H. Bemrose, J.P., Vice-President,
in the Chair.

James Douglas Haworth, 28 Victoria Street, S.W., and Robert Wright, B.Sc., Giridih, E.I.R. (India), were elected Fellows of the Society.

The List of Donations to the Library was read.

Mr. E. T. Newton, in exhibiting a series of small mammalian and other remains from the rock-shelter of La Colombière, near Poncin (Ain), said that, during the year 1913, Dr. Lucien Mayet and M. Jean Pissot were working systematically at the prolific deposits of this locality, and towards the end of the year made known the discovery of a number of incised bones and stones, representing the human form as well as

several animals. This discovery was published in the C. R. Acad. Sci. Paris (vol. clvii, p. 665), and some account of it, with several figures, appeared in the 'Illustrated London News' for November 1st, 1913.

The upper part of the deposit is referred to the Neolithic and Magdalenian ages: but below this, at a depth of $6\frac{1}{2}$ feet, a bed (10 inches thick) was found, which yielded the incised drawings mentioned above, as well as numerous mammalian remains and flint-implements; and this is regarded as of Aurignacian age. Immediately below the last-mentioned bed a deposit of sand and small rock-fragments was penetrated to a depth of 10 feet, and this deposit, also referred to the Aurignacian, was found to contain an enormous number of bones of small mammals and other animals. Some twenty species have already been recognized by the discoverers.

The large number of small bones now shown were obtained by the exhibitor in sifting about 1 cubic foot of this lower, remarkably prolific, deposit, which had been sent to him by Dr. Lucien Mayet, of Lyons.

The following communication was read:—

'On an apparently Palæolithic Engraving on a Bone from Sherborne (Dorset).' By Arthur Smith Woodward, LL.D., F.R.S., Pres.G.S.

In addition to the exhibit described above, the following specimens, etc. were exhibited:—

Incised drawing of a horse on bone, and remains of Pleistocene mammals from Sherborne (Dorset), exhibited by the President, in illustration of his paper.

Specimen of kaolinized Lower Kinderscout Grit from Bamford Edge (North Derbyshire), exhibited by Dr. Herbert Lapworth, Sec.G.S., M.Inst.C.E.

Lantern-slides of footprints of *Iguanodon*, etc. from the Wealden Beds of Sussex, exhibited by Charles Dawson, F.S.A., F.G.S.

Geological Survey of Scotland: 6-inch map, Sheet 11 (S.W.), Lanarkshire, 2nd ed. 1911; presented by the Director of H.M. Geological Survey.

March 25th, 1914.

Dr. A. Smith Woodward, F.R.S., President, in the Chair.

Sydney Lipscomb Elborne, B.A., Wootton House, Peterborough; Albert Farquahar, Waverley, Sandwich (Kent); and John William Dudley Robinson, B.Sc., 138 Portsdown Mansions, Maida Vale, W., were elected Fellows of the Society.

The List of Donations to the Library was read.

The PRESIDENT announced that the Council had awarded the Proceeds of the Daniel Pidgeon Fund for the present year to PERCY GEORGE HAMNALL BOSWELL, B.Sc., F.G.S,, who proposes to investigate the Stratigraphy and Petrology of the Lower Eocene Strata of the North-Eastern Portion of the London Basin.

Prof. J. W. JUDD, C.B., F.R.S., gave the following general account of the Geology of Rockall:—

'Rockall is a small isolated rock in mid-Atlantic, lying 184 miles west of St. Kilda; it has a circumference of only 100 yards and a height of 70 feet, and, except in the very calmest weather, is quite inaccessible. It is the haunt of sea-birds and, with its whitened top, resembles a sailing ship, for which it has often been mistaken. The rock rises from a bank (the "Rockall Bank") upon which there are several dangerous reefs.

'More than 300 years ago it was reported that a large island occupied the site of Rockall, and, for a hundred years or more, all Atlantic charts represented this island, which was named "Busse Island," with a number of other islands and islets, as present in the North Atlantic. Taking these supposed facts in connexion with the famous classical stories of an "Atlantis," the theory was often advanced that the North Atlantic was an area of subsidence, and that the reported islands—and, in the end, Rockall—were the last vestiges of the famous vanished continent. Modern research has, however, quite disposed of this fantastic theory.

'Nevertheless, Rockall is of considerable interest, especially to geologists. In 1810 Basil Hall, then a young officer in H.M.S. *Endymion*, obtained a fragment from this rock, which later found its way into the collection of the Geological Society. More than 30 years afterwards, the specimen was recognized; it was then mislaid for another 30 years, and in 1895 was brought to me by the late Prof. T. Rupert Jones.

'He not only carefully studied all the literature connected with Rockall, but was able to trace two other specimens of the rock, the loan of which he obtained and brought to me. They had been procured by two of the officers of H.M.S. *Porcupine* in 1868 during the survey of the North Atlantic. The microscopic study of these specimens shows that in Rockall there exist rocks of exceptional interest, which are not represented in our islands, but have analogues in the Christiania district of Norway, where they have been so well studied by Prof. W. C. Brögger. These rocks, as shown by microscopic study and by a chemical analysis made by Mr. Makins, consist essentially of three minerals—quartz, the felspar albite, and the rare soda-pyroxene ægirite, with its dimorphous form acmite. The rock, therefore, resembles the soda-granite and the grorudite of Prof. Brögger—but, in deference to the opinion of the distinguished Norwegian petrographer, a distinct name was given to it.

'In 1896 an attempt was made to obtain further specimens of the rocks of this islet by members of the Royal Irish Academy; but, although many valuable observations were recorded, it was found, after two voyages had been made to Rockall, quite impossible to land and obtain specimens.

'Dredging operations have yielded many specimens from the Rockall Bank, and these were examined by the late David Forbes and Prof. Grenville A. J. Cole. The abundance of basalt-fragments among these dredgings suggests the possibility of Rockall belonging to the same petrographical province as St. Kilda, Iceland, the Inner Hebrides, and the North of Ireland; hitherto, I believe, no rocks resembling "rockallite" have been found in this province On the other hand, the existence of borolanite and other alkaline rocks in the Northern Highlands suggests the possibility of Rockall being the western

extension of a much older province, which includes the Christiania district and the Scottish Highlands.

'Some months ago Prof. Iddings and Dr. Washington represented to me the desirability of a more detailed analysis of this rock. One of the two small fragments available was, by the advice of Prof. Watts, sent to America by the Council of the Imperial College of Science & Technology, to whom they belonged, and the paper now about to be read gives the result of the study of this minute specimen by Dr. Washington.'

The following communication was read:—

'The Composition of Rockallite.' By Henry Stephens Washington, Ph.D., For.Corresp.G.S.

Specimens of *Ostrea bellovacina*, with remains of the ligament, from the Oldhaven Beds at Beckenham (Kent), were exhibited by R. W. Pocock, B.Sc., F.G.S.

A geological map of the Vâlenii de Munte, on the scale of 1 : 50,000, 1911, presented by the Director of the Geological Institute of Rumania, was also exhibited.

April 8th, 1914.

Dr. A. Smith Woodward, F.R.S., President,
in the Chair.

The List of Donations to the Library was read.

The following communications were read:—

1. 'The Evolution of the Essex River-System, and its Relation to that of the Midlands.' By John Walter Gregory, D.Sc., F.R.S., F.G.S., Professor of Geology in the University of Glasgow.

2. 'The Topaz-bearing Rocks of Gunong Bakau (Federated Malay States).' By John Brooke Scrivenor, M.A., F.G.S.

The following specimens, lantern-slides, etc., were exhibited:—

Specimens of pebbles from the Essex gravels, and lantern-slides, exhibited by Prof. J. W. Gregory, D.Sc., F.R.S., F.G.S., in illustration of his paper.

Rock-specimens and microscope-sections exhibited by J. B. Scrivenor, M.A., F.G.S., in illustration of his paper.

Geological map of Austria-Hungary: 1 : 75,000, Sheets Iglau, Wels–Kremsmünster, Enns–Steyr, and Kirchdorf, 1913. Presented by the Director of the K.-k. Geologische Reichsanstalt.

April 29th, 1914.

Dr. A. Smith Woodward, F.R.S., President; and afterwards William Hill, Vice-President, in the Chair.

Frederick John North, B.Sc., Assistant in the Geological Department of the National Museum of Wales, Cardiff, 188 Farmers Road, Camberwell, S.E.; Ernest Proctor, Assistant Demonstrator in Geology, Imperial College of Science & Technology, 27 Holmby Street, Burnley (Lancashire); and Arthur Charles Varah, 7 Britnall Street, Sheffield, were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communications were read:—

1. 'On the Lower Jaw of an Anthropoid Ape (*Dryopithecus*) from the Upper Miocene of Lérida (Spain).' By Arthur Smith Woodward, LL.D., F.R.S., Pres.G.S.

2. 'The Structure of the Carlisle-Solway Basin, and the Sequence of its Permian and Triassic Rocks.' By John Walter Gregory, D.Sc., F.R.S., F.G.S., Professor of Geology in the University of Glasgow.

The following specimens and maps were exhibited:—

Specimens of the left ramus of the mandible of a young Chimpanzee, the left ramus of the mandible of Man, and the left ramus of the mandible of *Dryopithecus fontani* Lartet, from the Upper Miocene of Seo de Urgel, Lérida (Spain). Exhibited by the President, in illustration of his paper.

Specimens of Carboniferous sandstone from Kirtlewater, Redkirk, near Gretna, exhibited by Prof. J. W. Gregory, D.Sc., F.R.S., F.G.S., in illustration of his paper.

Geological Survey of Ireland: Sheet 11, 1913; map on the scale of 4 miles to the inch, or 1:253,440. Presented by the Director of that Survey.

Geological Survey of Scotland: Sheet 11 (S.W.), Lanarkshire, 1911; map on the scale of 6 inches to the mile, or 1:10,560. Presented by the Director of H.M. Geological Survey.

Geological Survey of New Jersey: geological map of New Jersey, 1910–12; on the scale of 4 miles to the inch, or 1:253,440. Presented by the Director of that Survey.

May 13th, 1914.

Dr. A. Smith Woodward, F.R.S., President,
in the Chair.

The List of Donations to the Library was read.

The President mentioned that, on the proposition of Mr. R. H. Tiddeman, President of the Yorkshire Geological Society, a conference would be held in Leeds next autumn to discuss thoroughly the Glacial phenomena of the North of England.

Mr. John Parkinson exhibited (*a*) a few specimens of the old lacustrine beds from the neighbourhood of Lake Magadi, on the borders of British and German East Africa; and (*b*) specimens of soda and of silica from the Lake itself. The former consist of unconsolidated ash, fine silts with *Planorbis*, and diatomite. Probably these beds, in places, are over 100 feet thick. With the soda is associated silica, which fringes some fault-scarps and forms narrow ridges in the Lake itself.

The following communications were read:—

1. 'The Scandinavian Drift of the Durham Coast, and the General Glaciology of South-East Durham.' By Charles Taylor Trechmann, B.Sc., F.G.S.

2. 'On the Relationship of the Vredefort Granite to the Witwatersrand System.' By Frederick Willoughby Penny, B.Sc., F.G.S.

In addition to the exhibit described above, the following specimens and maps were exhibited:—

Specimens of splintered flints, Scandinavian rocks, and Pleistocene shells from the Durham coast, and lantern-slides, exhibited by C. T. Trechmann, B.Sc., F.G.S., in illustration of his paper.

Rock-specimens and microscope-sections, exhibited by F. W. Penny, B.Sc., F.G.S., in illustration of his paper.

Geological Survey of Sweden: Maps Nos. 135, 138, 141, 146, & 149, on the scale of 1:50,000, 1909–1913; presented by the Director of that Survey.

May 27th, 1914.

Dr. A. Smith Woodward, F.R.S., President,
in the Chair.

Andrew Russell, Beerbhoom House, Asansol (Bengal), was elected a Fellow of the Society.

Dr. Friedrich Johann Becke, Professor of Mineralogy in the Imperial & Royal University of Vienna (Austria); Dr. Thomas Crowder Chamberlin, Professor of Geology in the University of Chicago (Illinois), U.S.A.; Dr. Franz Julijevich Lœwinson-Lessing, Professor of Mineralogy & Geology in the Polytechnic Institute, St. Petersburg (Russia); Dr. Alexis Petrovich Pavlow, Professor of Geology & Palæontology in the Imperial University of Moscow (Russia); and Dr. William Berryman Scott, Professor of Geology in the Princeton University, Princeton (New Jersey), U.S.A., were elected Foreign Members of the Society.

Dr. Paul Choffat, Geological Survey of Portugal, Lisbon; and Dr. Charles R. Van Hise, President of the University of Wisconsin, Madison (Wisconsin), U.S.A., were elected Foreign Correspondents of the Society.

The List of Donations to the Library was read.

The following communications were read:—

1. 'On the Development of *Tragophylloceras loscombi* (Sow.).' By Leonard Frank Spath, B.Sc., F.G.S.

2. 'The Sequence of Lavas at the North Head, Otago Harbour, Dunedin (New Zealand).' By Prof. Patrick Marshall, M.A., D.Sc., F.G.S.

Protoconchs and young specimens of *Tragophylloceras loscombi* (Sowerby), as also lantern-slides, were exhibited by L. F. Spath, B.Sc., F.G.S., in illustration of his paper.

June 10th, 1914.

Dr. A. Smith Woodward, F.R.S., President, in the Chair.

The List of Donations to the Library was read.

The Names of certain Fellows were read out for the first time, in conformity with the Bye-Laws, Sect. VI, Art. 5, in consequence of the Non-Payment of the Arrears of their Contributions.

The following communication was read:—

'The Ballachulish Fold near the Head of Loch Creran (Argyllshire).' By Edward Battersby Bailey, B.A., F.G.S.

Sir Douglas Mawson gave an account of the Geology and Glaciation of the Antarctic Regions, as observed in his recent

Expedition, and exhibited a series of magnificent lantern-slides, many of which reproduced the natural colouring by direct photography. A unanimous vote of thanks proposed by the PRESIDENT, and seconded by Dr. J. J. H. TEALL, was tendered to Sir Douglas Mawson, by whom it was briefly acknowledged.

June 24th, 1914.

Dr. A. SMITH WOODWARD, F.R.S., President,
in the Chair.

Walter Daniel Gove, 1 Riverview Road, Chiswick, W.; Campbell Murray Hunter, M.A., Assoc.M.Inst.C.E., 78 Finchley Road, N.W.; W. J. Jones, Lecturer on Mining & Geology to the Glamorgan County Council, Pleasant View, Graig Cefnparc, near Swansea; Frank Leslie Morgan, B.Sc., Madeley (Shropshire); and Edgar Schofield, The Rosary, Leventhorpe, Woodlesford, Leeds, were elected Fellows of the Society.

The List of Donations to the Library was read.

The Names of certain Fellows were read out for the second time, in conformity with the Bye-Laws, Sect. VI, Art. 5, in consequence of the Non-Payment of the Arrears of their Contributions.

The following communications were read:—

1. 'The Paradoxidian Fauna of a Part of the Stockingford Shales.' By Vincent Charles Illing, B.A., F.G.S.

2. 'The Trilobite Fauna of the Middle Cambrian of the St. Tudwal's Peninsula (Carnarvonshire).' By Tressilian Charles Nicholas, B.A., F.G.S.

The following specimens, etc., were exhibited:—

Specimens of trilobites, lantern-slides, and diagrams, exhibited by V. C. Illing, B.A., F.G.S., in illustration of his paper.

Specimens of trilobites, exhibited by T. C. Nicholas, B.A., F.G.S., in illustration of his paper.

ADMISSION AND PRIVILEGES

OF

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The Library is open on Week Days to the Fellows between the hours of 10 and 5 (except on Saturdays, when the hours are from 10 to 1, and except during the fortnight commencing on the first Monday in September; see also next page), and on Meeting-Days until 8 P.M. Under certain restrictions, Fellows are allowed to borrow books from the Library.

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CONTENTS.

PAPER READ.

[The Editor of the Quarterly Journal is directed to make it known to the Public that the Authors alone are responsible for the facts and opinions contained in their respective Papers.]

*** The Council request that all communications intended for publication by the Society shall be clearly and legibly written on one side of the paper only, with proper references, and in all respects in fit condition for being at once placed in the Printer's hands. Unless this is done, it will be in the discretion of the Officers to return the communication to the Author for revision.

The Library at the Apartments of the Society is open every Week Day from Ten o'clock until Five, except on Saturdays (when the hours are from 10 to 1), and except during the fortnight commencing on the first Monday in September, when the Library is closed for the purpose of cleaning. The Library is open until Eight P.M. on the Days of Meeting for the loan of books, and from Eight P.M. until the close of each Meeting for conversational purposes only.